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Some properties of the soil solution and the colloids in certain Iowa soils

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SOME PROPERTIES OF THE SOIL SOLUTION AND THE COLLOIDS IN CERTAIN IOWA SOILS

By

Gordon B. Killinger

A Thesis submitted to the Graduate Faculty
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INTRODUCTION

For many years soil investigators have realized the importance of the soil solution in relation to soil fertility. The composition, concentration, and quantity of soil solution determine to a large extent the productiveness of our soils. Generally speaking we know that such cations as calcium, magnesium, sodium, potassium, and others are present in soil solutions, and that these cations are generally associated with chlorides, phosphates, nitrates and carbonates.

There are many agencies which act on the minerals in the soil to make them become available for plant use. An important one is the carbon dioxide given off by plant roots through respiration and by microorganisms through the decomposition of plant residues. Chemical reactions taking place in the soil at all times have their effect on the availability of the plant food elements. Physical relationships when altered tend to change the soil solution, and in general it might be said that any change in the soil by any agency must as a consequence alter the make-up of the soil solution.

The soil solution is a dynamic system, continually changing in composition, concentration, and

quantity. The amount of solution may be decreased in the soil by: (1) run-off, (2) percolation, (3) transpiration, and (4) evaporation. The solution when at its smallest volume is the most concentrated with plant food minerals. The concentration of the soil solution may be decreased by utilization by plants or losses in drainage water or it may be increased through biological action. The soil solution may gain in volume by the artificial addition of water, by rainfall, by capillary action or by a rise in the ground water level. As the volume of solution increases, the total quantities of minerals in solution also increases but not proportionately.

Numerous investigators have tried to extract the soil solution but their results show only too well that the process of extracting the solution in an unaltered condition is a difficult problem. If it is impossible with our present knowledge of soils to extract the true soil solution, then we must accept the solution as it is extracted by present methods until more desirable methods have been perfected. Any method used will have its disadvantages and all methods now employed are open to considerable criticism.

Centrifuging the soil, soil percolation, various pressure methods, suction applied to a porous

tube in the soil, adsorption by filter paper, lysimeter studies, and displacement with all types and classes of liquids have been tried, and have contributed information of value to our knowledge concerning the composition and concentration of the soil solution. At the present time a water extract of the soil is being used most widely, and it is probably as representative of the true soil solution as the solution obtained by most of the other methods. Obviously, we have not yet developed a method for obtaining the soil solution in an unaltered state. A field test for obtaining the soil solution may be better than a laboratory test, in that it might give a solution more nearly the same as the original solution in the soil.

The soil solution is very closely related to the colloidal complex of the soil. As the colloidal complex varies, the soil solution tends to vary also. The colloids function in the soil to prevent minerals from leaching out of the soil, and to supply the solution with the minerals when the solution has become diluted. The colloidal complex is also important as the seat of base exchange reactions in soils.

The colloidal fraction of the soil is generally considered the most reactive portion of the

soil and its importance has been emphasized by many investigators. We still know relatively little, however, concerning the actual mechanism of the reactions brought about by the colloids. A certain percentage of colloidal material may improve the physical condition of the soil. This amount of colloidal material may or may not be optimum for other reactions in the soil, or for the best tilth for crop growth. Colloids are active in the role of base exchange, holding the various ions chemically by absorption. When the proper ions have been added to a soil in solution there is an exchange of ions in which the ion added takes the places of some other ion already present. The colloids are said to be the binding power of the soil. It might be said of the colloids that they assume the role of a soil filter, that is, they hold by one means or another the various mineral elements which would otherwise be leached down in the soil to such depths that they would have no value as plant nutrients. The soil colloids have been divided into two fractions; namely, the organic and the inorganic.

Many years ago, Jethro Tull expressed the opinion that the plants take up the finely divided particles of soil through their roots as food. This theory although incorrect may serve to indicate to some

extent the importance of the colloidal complex.

Bacteriologically the colloids play a very important part in the soil. Each colloidal particle may assume the role of a nucleus for a great number of bacteria that obtain their mineral and organic constituents from the colloidal particle or from the minerals in the moisture film surrounding the particle. Thus, the colloids in the soil serve as a habitat for both aerobic and anaerobic organisms.

It can readily be seen that there are still many problems to be solved concerning the nature and properties of the true soil solution and the colloidal complex of the soil. The purpose of the work reported here was to determine some of the relationships between these two closely interrelated fractions of the soil. The importance of the soil solution in a system of soil mapping, its analysis in comparison with the analysis of the soils, and its relation to the exchange capacity of the soil have been studied.

REVIEW OF LITERATURE

METHODS FOR EXTRACTING THE SOIL SOLUTION

A number of methods for extracting the soil solution in an unaltered state have been proposed during the past thirty years. The solutions obtained by the different methods were seldom of the same composition. For the past ten years a 1:5 water extract method for obtaining the soil solution has come into prominence and is probably being used more at the present time than any other method. Early investigators as well as the more recent workers have realized that there is a definite relation between the soil solution, the soil colloidal matter, and base exchange.

One of the earliest pieces of work carried on in this country was that by Briggs and McCall (14) in 1904. These investigators used a porous porcelain tube buried in the soil and applied suction by means of an exhausted flask. By this means they were able to secure small quantities of the true soil solution. This method had the advantage that it could be used in the field as well as in the laboratory and the solution obtained from the soils in the field was found to have very nearly the same composition as the solution obtained from the

same soil in the laboratory.

In 1912, Cameron (23) concluded from some lysimeter studies that the solution obtained in the drainage was not identical with the true soil solution. He found that the composition of the lysimeter drainage water did not give direct quantitative information as to the concentration of the soil solution. From this it would seem that the lysimeter studies might be of significance if interpreted properly, but were of doubtful value if used as representative of the true soil solution.

Later, Morgan (56) concluded that the solution obtained by an oil pressure method gave the true soil solution. In this method he applied five hundred pounds of pressure instead of suction which had been used previously. The soil was placed in a cylinder and a layer of paraffin oil added after which the pressure was applied and the soil solution was pressed out. Morgan was able to extract from 2 to 70 per cent of the moisture from the soil by this method.

In 1918, Lipman (49) devised what he termed a new method for extracting the soil solution. He had large cylinders specially prepared for this work. The soil was placed in these cylinders and subjected to

53,000 pounds of pressure per square inch. This proved to be a satisfactory method for the extraction of the soil solution. Other pressure equipment had been used before this time but no pressure as high as this was used.

Bouyoucos (9) conducted some investigations using a freezing point method for determining the concentration of the soil solution. He found that the data secured from the freezing point method correlated very closely with the data secured from a 1:5 water extract method. Different types and classes of soils were studied and he was able to differentiate the soils by the freezing point method. Soils treated with various fertilizers gave various freezing points. He was able to tell by the freezing point the rate at which the various minerals went into solution after being applied to the soil.

In 1920, Hoagland, Martin and Stewart (39) compared the soil solution as determined by the freezing point method with various soil extracts. They found the 1:5 water extract contained from one and five-tenths to five times the amount of total solids contained in the soil solution as calculated from the freezing point data on a moist soil. From their work they concluded

that if a 1:5 water extract was to be used the soil should be shaken with distilled water for two to three hours and allowed to stand for one week before filtering. If a 1:1 water extract was to be used, the soil and water needed to stand for only a day or two. They found that the actual concentration of the solution was governed principally by the equilibria existing between the dissolved substances and the immediately soluble or absorbed substances. The concentration of the solution at any given moment was found to depend upon the resultant of the cumulative effect of the continuously varying solvent on the soil minerals.

The following year, Burgess (21) showed by a comparison of the direct pressure method with the 1:5 water extract method that in nearly every case more of the soluble plant food elements were held in the 1:5 water extract, than in the soil solution obtained by the direct pressure method. A wide variety of California soils were analysed for calcium, magnesium, potassium, nitrates, phosphorus and sulfates. These elements did not all vary to the same extent; the potassium dissolved in the soil extract was, on an average, five times as much and the phosphorus was thirty-five times

as much in the extract as in the soil solution. By comparing the 1:5 water extract with conductivity measurements of soil solutions, Burgess secured data which were in close agreement with the known productivity of the several soils examined. Brief mention was made of certain experiments in which the oil pressure method was found to be of questionable value for securing satisfactory quantities of a uniform soil solution from certain soils.

About the same time, Parker (59) studying the concentration and composition of the soil solution found that ethyl alcohol used as a displacing agent yielded a solution which had about the same composition as the 1:5 water extract or the soil solution. He found that ethyl alcohol was a more satisfactory displacing liquid than water, methyl alcohol, acetone, or liquids non-miscible with water. The composition of the soil solution obtained by displacement was not influenced by the displacing liquid used. The concentration of the displaced solution was found to be inversely proportional to the moisture content of the soil. It was found that the freezing-point method did not give a measure of the concentration of the soil solution directly in the soil at ordinary moisture content. It was only at high moisture contents, probably only above saturation that

the freezing-point method gave a measure of the concentration of the soil solution. The freezing-point depression due to solid material, at the moisture equivalent, was found to be very nearly a constant for a number of soils.

Stewart (73), in 1921, reported that the 1:5 water extract was the most adequate criterion in the study of the deficiencies of productivity of soils.

Martin and Burd (54) reported on a modification of the Parker displacement method for obtaining the soil solution. They found that, aided by positive air pressure never exceeding 100 pounds per square inch and using distilled water as the displacing medium, solutions displaced from closely compacted columns of soils had a constant concentration, when the volume was from 50 to 80 per cent of the original moisture in the soil. The concentrations of solutions displaced from the same soil at different moisture contents were inversely proportional to the total moisture. When the displaced solution from a soil was used as the displacing agent on another column of the same soil at the same moisture content, the displaced solution was identical with the displacing agent, and the latter passed through the soil unchanged, indicating that the displaced solution has the same concentration and composition as the solution

with which it came in contact in the soil. Comparisons made between displaced solution and the water extracts of the same soils at the same moisture content indicated that either method gave the same concentration of nitrates and chlorides, and both showed very similar concentrations of calcium and magnesium. The extraction method in every case indicated a higher concentration of potassium and phosphoric acid than was present in the displaced solution. In the case of the latter the excess was directly proportional to the excess water used in the extraction.

About this same time, Tulaikov and Kuzmin (78) developed a method for obtaining the soil solution in comparatively large quantities more quickly and accurately than could be done with other methods. By this method the atmosphere within a hollow cylinder placed within a definite volume of soil was exhausted. The pressure of the outer atmosphere displaced the solution from the soil into this cylinder as soon as sufficient vacuum had been produced. To obtain sufficient soil solution from a soil with a moisture content of less than 50 per cent saturation and to counteract the molecular forces in the soil which tended to hold small quantities of moisture the soil was pressed by means of a common press in addition

to the air exhaustion. Tests of this method indicated that it permits of extraction from varying quantities of soil and that more soil solution may be obtained than by the other methods. Comparatively little time was consumed by this method and the soil solution obtained was of constant concentration in the consecutive portions.

Greaves and Hirst (32) have reported that clear soil extracts may be obtained by adding two grams of lime, ferric sulfate, ferric alum, sodium alum, or potassium alum to the soil-water mixture, by filtering thru the Pasteur-Chamberlain filter, or by centrifuging. The last three procedures gave a clear solution with a minimum loss of salt. Lime, ferric sulfate, and ferric alum caused a considerable loss of nitrates. These workers claim that nothing is to be gained by agitating the soil and water for more than five minutes provided the soil is finely divided and the solution is vigorously shaken.

Water displacement of the soil solution and the soil solution obtained by pressure were investigated by Burd and Martin (19) in 1932. Their studies conducted on three sandy soils and two clay loams from California showed that the use of a positive air pressure on closely packed soils decreased the time of recovery and increased the yield of solution obtained by water displacement.

Successively displaced solutions of equal electrical conductivity were obtained from each soil. The concentration thus measured was in each case the same as that of the liquid obtained without the use of displacing water. Concentrations of individual ions in successive portions of displaced solutions were uniform in soils at optimum and at half optimum moisture. There was an inverse proportion between total moisture content of the soil and the concentration of the displaced solution as indicated by measurement of specific resistance. When the solution displaced by water from a given mass of soil was used as the displacing agent on another portion of the same soil, the newly displaced solution had the same concentration of electrolytes as the displacing solution. This was taken to indicate that the displaced solution had the same concentration as the solution with which it came in contact in the soil. Evidence was presented which tended to show that compacted soils become completely saturated during displacement, and that the mechanism of displacement consists in an actual translocation of successive layers of liquids.

In the same year, Hibbard (37) working in California, on nine different alkali soils, compared the solutions obtained by a 1:5 water extract and by the

displacement method. The data obtained indicated that the water extract does not represent the actual condition of the solution in the soil. Carbonates, bicarbonates, and phosphates were greatly over-estimated in the water extract. Chlorides, nitrates, and sodium may be approximately correct; sulfates and potassium are likely to be much over-estimated; and calcium or magnesium may be either high or low. It was also found that the actual concentration of solutes in the true soil solution may be much greater than is generally realized by one accustomed to thinking in terms of the amounts found in 1:5 water extracts. The geochemical classification showed that the water extracts contained relatively larger proportions of sodium salts and less of calcium and magnesium salts than the true soil solution. The latter made the soil appear more favorable for plant life than did the water extraction method.

Pierre and Parker (60), in 1926, successfully demonstrated the use of collodion sacks in obtaining a clear soil extract for the determination of water soluble constituents. Prior to this time Parker had used the Pasteur-Chamberlain filter and obtained large amounts of a clear extract, but it could not be used for hydrogen-ion work nor where phosphorus was to be determined.

The length of time that the soil was allowed to remain in these collodion sacks depended upon the minerals present; usually from two to three hours was sufficient time. This method was found suitable for obtaining large amounts of clear extract from which all water-soluble constituents could be determined by even the most sensitive colorimetric method.

Gedroiz (30), in 1929, working with soil solutions, changed the ratio between water and soil and investigated the solubility of soil compounds of saline and non-saline soils. He found these water-extracts were an invaluable aid in differentiating these two types of soils.

Schreiner and Failyer (68) experimented on the use of the 1:5 water extract on moist and dry soil. They found that minerals in such an extract were present in such small quantities that it was difficult to determine them accurately.

In 1918, Burd (17) reported that water extractions of soils might be successfully used as criteria for the crop producing power. He stated that there was always present in the soils enough water soluble minerals to supply the immediate needs of the plants. From his data it was concluded that the optimum concentration

varies with every soil. By comparing the figures expressing these characteristics with similar data derived from soils whose productive power was known, he was able to predict within reasonable limits the crop producing powers of the soil.

THE IMPORTANCE OF A CHEMICAL ANALYSIS OF SOILS AND SOIL SOLUTIONS

As early as 1903 Hopkins (41) suggested that the chemical analysis of the soil or fractions from the soil, serve as the foundation upon which methods of soil treatment might be worked out.

Many of the earlier soils workers were of the opinion that the soil should be analyzed if one was to know anything as to its deficiencies or its productiveness. King (48) reviewed the early work of Grouven, Peter, Schultze and others and concluded that a highly productive soil would show a high content of the necessary plant food constituents.

Hall, Brenchley, and Underwood (34) of England compared water extracts and the drainage waters of the Rothamsted experiment plats with the total composition of the soil and found that there was no relation between the total composition and the water extract, but that there was a significant relation between the fertilizers

applied and the composition of the water extract and the drainage water. At about this same time Mitscherlich (55) was able to dissolve the minerals from the soil with the aid of carbonated water and distinguish between fertilized and unfertilized soils. His work tended to show some relationship between the total chemical composition of the soil and the amount of minerals which could be readily dissolved out.

Thorne (75) concluded that the chemical study of the soil and of the soil solution was necessary before any worth while recommendations for the improvement of a soil might be had.

Some of the investigations carried on by Cameron (22) indicated that a study of the soil solution at any particular time was of little value, due to its dynamic condition. He found that the character of the soil solution was dependent upon the minerals in the soil, but that the same amounts of minerals in one soil would tend to yield a solution widely different in concentration than that obtained from another soil.

Ames and Gaither (1) showed rather definitely that the excesses and deficiencies of a soil could be accurately measured by analysis of the soils. Hall and Russell (35) were of the same opinion, but in addition

they insisted that the physical character of the soil be considered. The mechanical analysis should certainly be correlated with the chemical analysis because it is the physical characteristics of the soil that regulate the water supply and, therefore, the temperature and air supply. They also affect the ease of cultivation, and in fact play a large part in determining the value of a soil.

Robinson (63) found no dependence of the soil solution upon the total composition of the soil, except in the case of the very soluble ions. He explains this by showing that the soils are made up of a number of different minerals, and that the reaction between water and these minerals is irreversible and one of decomposition. This would suggest that if the condition outside the water-mineral mixture was kept constant, then the quantity of soluble matter would depend upon the kind and extent of the mineral surface exposed, the protection of the film of colloidal residues, and the capacity of these colloidal residues for adsorption. When these facts are considered, it would seem that there can be little correlation between the total composition of the soils containing much undecomposed minerals and the water extracts. It is certain that any solution formed

by the action of water upon soil minerals is subject to considerable modification by the colloidal matter.

The mineral constituents of some soil solutions were determined by Cameron and Bell (24). They found that nearly all soils had some of the same mineral species from which the soluble fractions were dissolved. It was their opinion that the soil solution was practically the same in all soils, and that this concentration would be great enough for crops for many years.

Davis (26) made use of the electrolytic bridge for determining soluble salts in some soils. The resistances of various soil extracts were measured and these in turn compared with the total soluble salt content of the corresponding soils. He found a very good agreement between the resistance offered by a solution and the amount of soluble salts present.

In 1924, Atkins (4) used the electrical conductivity measurements of extracts for detecting the fertility of a number of soils. He recognized that a high electrical conductivity might only indicate the presence of an excess of salts and did not necessarily indicate a good soil. However, the results were taken to indicate that a rapid increase in conductivity as the

extraction was prolonged indicated increased solubility, partly through bacterial action, and might be considered as a useful indication of fertility. On the other hand, a low conductivity, which remained low on continued extraction, denoted a soil so low in soluble elements as to be unproductive.

Burd (16) in 1918, claimed that either a chemical or a mechanical analysis of a soil was inadequate for estimating soil fertility. He pointed out that field studies or the past performance of a certain soil was also necessary in order to make recommendations.

Some early analytical work on soils was carried out by Robinson (62) who analyzed a great many soils from all parts of this country. Later Robinson and Holmes (64) analyzed a Carrington loam soil taken from Iowa which was found to contain: 77.28 per cent of SiO_2, 8.93 per cent of Al_2O_3, 2.89 per cent of Fe_2O_3, 0.84 per cent of CaO, 0.54 per cent of MgO, 1.35 per cent of K_2O, 1.15 per cent of Na_2O, 0.14 per cent of P_2O_5, 0.27 per cent of nitrogen, and 32.4 per cent of colloidal material. A Marshall silt loam soil from Nebraska was found to contain: 72.06 per cent of SiO_2, 11.18 per cent of Al_2O_3, 3.66 per cent of Fe_2O_3, 0.90 per cent of CaO, 0.66 per cent of MgO, 2.66 per cent of K_2O, 1.02 per cent of Na_2O, 0.21 per

cent of P_2O_5, 0.23 per cent of nitrogen and 27.30 per cent of colloids.

Bear and Salter (6) found that the nitrogen-, phosphorus-, carbon ratio of a soil was more or less proportional on differently treated plots. They showed graphs which indicated that these three constituents parallel each other in variously treated soils.

Drachev (27) extracted a number of soils using various soil-water ratios. He found that the amount of salts extracted from soils with various amounts of water was proportional to the square root of the volume of water used. He also found a relationship between the amount of electrolytes dissolved out and the exchange capacity of the soil. He found correlations between the chemical composition of the soil and the composition of the water extracts.

SOIL COLLOIDS AND BASE EXCHANGE

The work of Van Bemmelen (79) in 1878 showed some of the importance of colloids in regard to base absorption. At that time very little was known about how or why bases were absorbed in the soil; however, many workers before this time had reported that when a base was applied to the soil they were unable to recover

all of the basic ions which had been applied. Van Bemmelen connected this base absorption with the zeolitic nature of some of the soil particles. He disproved the early idea that the replaceable bases were chemically combined with the soil but said that they were adsorbed or absorbed.

A little later, Van Bemmelen (80) found the colloidal silicates and colloidal humus formed in various proportions, a mass of colloidal complexes that controlled the composition of the soil solution. It was this early work of Van Bemmelen's that gave rise to the great amount of research on colloids and base exchange that was to follow.

Schloesing (65, 66, 67) was one of the first to call attention to the colloidal matter in soils. As early as 1874 he reported various percentages of colloids in a number of soils ranging from fine sands to very heavy clays. He considered the soil colloids to be a hydrous aluminum silicate ($Al_2O_3.2SiO_2.2H_2O$).

Briggs and McLane (15) extracted the soil solution and obtained the colloidal fraction from the soil by centrifuging at 2000 to 3000 times the force of gravity.

Green and Ampt (33) of England considered the soil colloids to be of much importance from the standpoint of the moisture relationship in the soil. They thought that the soil was composed of a bundle of capillary tubes through which the air and water moved but was controlled somewhat by the amount and kind of colloidal material present.

Stiles and Jorgenson (74) called attention to the complex character of the soil and emphasized the importance of colloidal substances in the soil in soil water investigations. They concluded that further study in soil physics would be necessary to clear up many of the points that were questioned at that time.

Bouyoucos' (10) investigations showed that the soil solution around the soil particles and in the very fine capillary spaces was less concentrated than the mass of the solution. From this it would seem that the colloids present in the soil probably absorbed some of the minerals from the solution with which it comes in contact.

Bilz (7) found that rock weathering resulted in the formation of complex colloidal silicates, which in the form of gels, covered the surface of the soil particles. This covering would thus influence the composition of the soil solution. From this it can readily be seen that the

colloidal silicates found at that time were involved in an exchange of ions or in the absorption of ions from the soil solution.

Keen (42) in England gave a critical discussion of some of the data obtained by Bouyoucos. He pointed out that it was not only the amount and concentration of the soil solution that fixes the freezing-point depression, but also the amount and kinds of colloidal material present in the soil.

In California, Martin and Christie (53) found that the amount of moisture which could be extracted from various textured soils was widely different. This was thought to be due to the holding or adsorption power of the colloids.

In 1920, Keen (43) concluded that a study of the soil from the colloidal point of view would be necessary to a clear understanding of the relationship between the soil and the soil solution.

The absorption by colloidal and non-colloidal soil constituents was reported by Anderson, Fry, Gile, Middleton and Robinson (2). They found that practically all the absorptive power of the soil was localized in the colloidal material. The colloidal material which has high absorptive power probably, therefore, acts to a

considerable extent as a regulator of the soil solution, influencing the kind and concentration of the various bases in true solution and affecting the rate at which the soil minerals decompose.

Truog (76) in a review of the various theories of how plants feed stated that the colloids remove any excess of minerals from the soil solution after fertilization and prevents loss by leaching. This assumption was based on the fact that the drainage water does not readily remove many of the plant food elements from the soil. It was found that in sandy soils, low in colloidal content, the minerals were readily dissolved out by the drainage water.

Hoagland (40) observed that the replaceable bases in the soil depended upon the nature of the colloidal constituents of the soil. He thought that by a study of the colloidal fraction it might be possible to predict in the field whether the particular soil in question was capable of developing an adequate soil solution.

Burd and Martin (18) pointed out that the soil solution was a dynamic system changing at all times. These changes were partially due to the exchange phenomena going on in the soil which is somewhat governed

by the concentration of the solution. Later, (20) they reported on data secured from solutions displaced from seven California soils. In this work they found that soils that were cropped for a number of years had a soil solution of lower concentration than a similar soil not cropped. This was due to the taking out of the plant food constituents by the crops and in turn they were not returned either by surface applications of fertilizers, nor were they released by the colloids of the soil.

Baver (5) emphasized the fact that the colloidal material is responsible for most of the physico-chemical phenomena observed in soils, and that the colloidal organic matter may be of major significance in this regard. The absorptive capacity of soils for cations was found to increase with the increases of organic matter.

In a presidential address to the American Society of Agronomy in 1930, Kelley (45) stated that he considered base exchange to be one of the important principles of soils. He showed that the base exchange compounds, or colloids, were of real significance in plant nutrition. He stated that the bases must constitute an integral part of the colloidal particles, and that the base exchange compounds were both amorphous and crystalline, but varied with the soils studied.

More recent work by Müller (57) showed that the base exchange of a soil is closely correlated with the degree of decomposition of the organic matter present. Materials such as peats were found to have a high base exchange capacity and the fresh materials such as straw and wood shavings had little or none. He found indications that lignin was largely concerned in base exchange in natural organic materials.

EXPERIMENTAL

The chemical analyses of soils and soil extracts were made in an effort to characterize more completely a number of important Iowa soils. The base exchange properties of the soils were determined and correlations made with the composition of the soils and of the soil extracts. Investigations of the relationships between the soil colloids and the microflora of the soils were also carried out.

CHEMICAL ANALYSES

Preliminary Studies on Soil Colloids

Some preliminary work on the colloidal properties of four soils from different sections of the state was carried out. These four soils, sampled in the fall of 1931, were Carrington loam, Webster silty clay loam, Cass loam and Tama silt loam, and are described as follows.

The Carrington loam is one of the most extensively developed soil types found in the state and is of drift origin. The surface soil of this type is a brown mellow loam, 14 to 18 inches in depth. The subsoil is a brownish-yellow to yellowish-brown sandy clay loam to sandy clay, occasionally showing some mottlings of gray in the lower depths. In some areas the lower subsoil is gritty and contains some gravel and sand. The topography of the

Carrington loam varies from undulating to strongly rolling. The drainage of the type in general is quite satisfactory. This soil is naturally a very fertile soil and crop yields are generally quite satisfactory. The soil contains considerable organic matter and is fairly well supplied with nitrogen and phosphorus.

The soil classified as the Webster silty clay loam is found in the Wisconsin drift area. It occurs principally in the lower flatter areas along the intermittent drainageways and in the depressed level sections of the uplands. The surface soil of the type is a black silty clay loam, 10 to 12 inches in depth. The subsoil is a dark brown to grayish-brown silty clay loam to silty clay to a depth of 20 to 24 inches. Below that point it becomes a grayish-brown to dark drab tenacious silty clay to clay, mottled with brown, gray and yellow. In the more poorly drained areas there is a high content of lime in the surface soil, and the lower subsoil is always rich in calcareous material. This soil type varies in topography from level to very gently undulating. The natural drainage of the soil is quite inadequate, and the installation of ditches and tile drainage is necessary if this land is to be used for general farm crops and yields are to be at all satisfactory in average seasons. This soil is well

supplied with organic matter, has a plentiful supply of nitrogen but does not have any large amount of phosphorus.

The soil classified as the Cass loam is a minor type found on first bottomlands. The surface soil of this type is a dark brown to black, friable heavy loam, from 10 to 15 inches in depth. This is underlaid by a light brown to brown loamy sand, mottled with faint gray and yellowish-brown. Iron stains occur in the lower part of the subsoil and there is considerable coarse material and very fine sand. In topography this soil is flat but drainage is good. It is subject to overflow and must be protected by levees if it is to be successfully cultivated in all seasons. The type is naturally productive, and in favorable seasons very satisfactory yields are secured. It is fairly well supplied with organic matter, nitrogen or phosphorus.

The Tama silt loam is found in the southcentral and eastcentral part of Iowa. It occurs at the heads of most of the small drainageways and is found on the rolling uplands and on the slopes separating the more level uplands from the lighter-colored, forested and more eroded hillsides. The surface soil of the Tama silt loam is a dark brown, friable silt loam, grading at 14 inches into a yellowish-brown silty clay loam. At 22 inches, the subsoil

is somewhat heavier in texture, becoming a silty clay, yellowish-brown in color. Occasionally below 30 inches, there are faint yellowish-brown mottlings and iron stains. In topography this soil is gently rolling and is well drained as a whole. Erosion occurs to some extent and on the steeper slopes the soil may vary from 2 to 6 inches in depth, and in some cases the lighter colored silty clay subsoil is exposed. The Tama silt loam is normally a productive type but it responds to applications of organic matter and phosphatic fertilizers.

Soils characteristic of each particular type were selected and carefully sampled. The upper 6 inches of the soil were taken, passed through a 60-mesh sieve and placed in 4-gallon jars which were kept in the greenhouse. The moisture content of the soils was maintained at approximately 50 per cent of the saturation capacity, with distilled water. Weeds and other growth were kept down by stirring the soil with a spatula once each week during the time the soils were being sampled.

These four soils were analyzed for colloids, total carbon, organic carbon and the pH was also determined. The data secured in these studies are shown in table I. The colloids were determined by the Bouyoucos (11) hydrometer method which consists in the placing of a known amount of

TABLE I

COLLOIDAL PROPERTIES OF FOUR IOWA SOILS

Soil Type	Percentage Composition							
	Colloids in soil	Total carbon in soil	Organic carbon in soil	Organic carbon in colloids	Organic matter which is colloidal	Colloidal matter which is organic	Colloidal matter which is inorganic	pH of the soils
Carrington loam	31.40	2.50	2.50	6.31	79.25	1.98	29.42	6.72
Webster silty clay loam	45.60	7.16	5.01	9.39	85.46	4.28	41.32	7.57
Cass loam	20.60	4.45	3.35	7.09	43.58	1.46	19.14	7.93
Tama silt loam	28.60	1.98	1.98	5.17	74.69	1.48	27.12	6.42

soil in the container of a malted milk machine and adding water until the container is about two-thirds full. This is allowed to stand for 15 minutes to permit of the slaking of the dry soil, then 5 cc. of solutions of sodium hydroxide and sodium oxalate are added and the malted milk machine is started and allowed to run for 10 minutes after which time the liquid is poured into a special cylinder, a hydrometer is placed in the cylinder and water added up to the 1000 cc. mark, after which the hydrometer is taken out and the soil-water mixture shaken. The mixture is allowed to settle for 15 minutes at the end of which time the hydrometer is placed in the solution, the reading taken, the temperature determined and the per cent of colloids is calculated from these data. The hydrometer used in this work is one specially prepared and calibrated to read directly the per cent of colloids.

The total carbon content of the soils was determined by the dry combustion method. The inorganic carbon was determined by the method of Schollenberger (70). The colloids from these soils were extracted by means of a super-centrifuge run at the rate of 40,000 revolutions per minute. The colloids were dried and the carbon content determined. The pH was determined by means of the glass electrode method. The results obtained are presented in

table I and the other data collected in table I were calculated from the colloids, total carbon and organic carbon.

The Webster silty clay loam had by far the highest colloid content, followed by Carrington loam, Tama silt loam and Cass loam in the order given. It would be expected that the Webster soil should have the highest colloidal content because of other physical characteristics of this soil, such as texture, structure and composition. The Webster silty clay loam was also highest in total carbon content with Cass loam, Carrington loam and Tama silt loam following in the order given. This might be expected too because the Webster silty clay loam is very high in organic matter. The Cass loam soil does not contain a high organic matter content but because of excessive drainage which tends to keep the soil dry and prevents extensive bacterial action the organic matter tends to accumulate at or near the surface of the soil. The Carrington loam is moderately level, has a rather clayey subsoil and is well drained. It might, therefore, be expected to have a high amount of total carbon. The Tama silt loam which has the lowest total carbon content is also subject to more leaching and washing than the other soils

due to its more rolling topography. In these four soils most of the carbon was found to be of an organic nature. The Webster silty clay loam which has a pH value of more than 7.0 contained 2.15 per cent of inorganic carbon. A large part of this was probably present in the form of calcium carbonate. The Cass loam, a bottomland soil, had 1.10 per cent inorganic carbon. The Carrington loam which is slightly acid contained negligible quantities of inorganic carbon and the Tama silt loam which is also acid contained no inorganic carbon.

The carbon present in the soil colloids after extraction from the soil was found to be chiefly in the organic form. This was due no doubt to the leaching out of the inorganic carbon during the course of extraction. The organic carbon content of the soil colloids was highest in the Webster silty clay loam being 9.79 per cent, in the Cass loam 7.09 per cent, in the Carrington loam 6.31 per cent, and in the Tama silt loam 5.17 per cent. These data also show that 85.01 per cent of the organic matter in the Webster silty clay loam was colloidal, 79.25 per cent in the Carrington loam, 74.69 per cent in the Tama silt loam, and 43.58 per cent in the Cass loam was colloidal. This might be explained by the difference in intensity of bacteriological action in the different soils.

The Webster silty clay loam contained 4.28 per cent of colloidal organic material, the Carrington loam 1.98 per cent, the Tama silt loam 1.48 per cent and the Cass loam 1.46 per cent. The Webster silty clay loam by calculation contained 41.32 per cent of inorganic colloidal material, the Carrington loam 29.42 per cent, the Tama silt loam 27.12 per cent and the Cass loam 19.14 per cent. These data correspond with the characteristics of these four soils as outlined in Iowa soil survey reports and it would seem possible to place each of these soils in their proper series on a basis of this study of the colloidal matter.

Chemical Composition of Soils

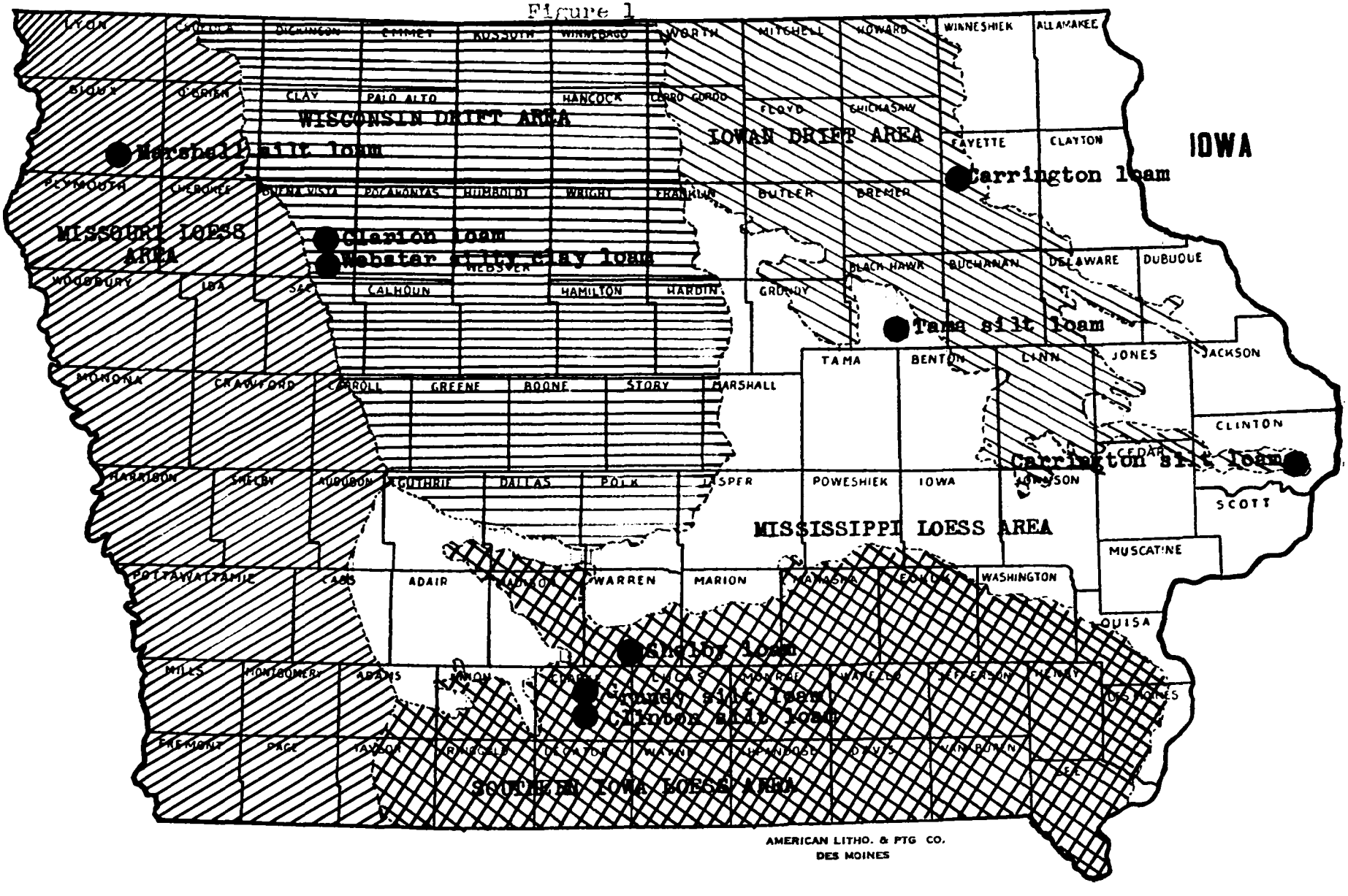
A complete analysis was made of nine Iowa soils sampled in the fall of 1932. This analytical work was done to determine whether or not there was any correlation between the soils and their water extracts.

The nine soils included the Carrington loam, Webster silty clay loam, and Tama silt loam but samples of these types were taken from different areas than were sampled in 1931 and the soils, therefore, might not have the same composition. The other six soils used in this work are classified as Shelby loam, Grundy silt loam,

Marshall silt loam, Clarion loam, Clinton silt loam and Carrington silt loam. These nine soils were taken approximately in the areas designated by the black points on figure 1.

The Shelby loam is a drift soil found chiefly in the central to south-central parts of Iowa. It is located on the rolling to rough uplands where the upper layer of loessial soil has been washed away. The surface soil of the Shelby loam to a depth of four to eight inches is a dark grayish-brown, finely granular, friable loam, containing some fine sand. The subsoil is a yellowish-brown granular silty clay loam. In some areas there is a layer separating the dark colored surface soil from the yellowish-brown subsoil which is somewhat lighter in color than the surface soil and gradually grades into a light colored subsoil. Below 18 to 24 inches the subsoil consists of glacial drift made up of fragments of many kinds of rock, usually reddish-brown or yellowish-brown in color and spotted with red, brown or gray. Small pockets of sand and gravel occur in the subsoil and boulders are quite frequently found. In topography the Shelby loam is strongly rolling to hilly and the drainage is good to excessive. This soil is subject to serious erosion and

Figure 1



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responds to liberal applications of organic matter and phosphatic fertilizers.

The Grundy silt loam is a loessial soil found extensively in the Southern Iowa loess area. The surface soil of the Grundy silt loam is a very dark grayish-brown, friable silt loam extending to a depth of about 12 inches. It is mellow when dry but sticky and almost black when wet. In the lower part of the surface soil faint gray markings appear. Between 12 and 17 inches, the material is silty clay loam slightly browner in color than the surface soil. From 17 to 25 inches the soil is a heavy clay, dark brown in color on the exterior of the particles but somewhat gray to yellow or brown in the interior. The coloring is evidently due to a coating of organic matter which has moved down from the surface soil. The topography of this soil is level to gently rolling and the drainage is somewhat variable. It is only on the more level areas that artificial drainage is necessary. In the more strongly rolling areas some erosion has occurred. The Grundy silt loam is usually found to be in need of farm manure and phosphatic fertilizers are also recommended.

The Marshall silt loam is a loessial soil found in the Missouri loess soil area. The surface soil of the Marshall silt loam is a very dark grayish-brown, friable

silt loam, appearing almost black when wet. It extends to a depth of about 5 inches. The subsurface layer is similar in color to the surface soil but consists of a slightly heavier silt loam. This layer on the smoother uplands is about 7 inches in thickness. On the slopes the surface soil is thinner and on small areas on the steep slopes, on the tops of sharp knolls and ridges, the darker colored surface soil has been removed and the lighter colored subsoil exposed. On the more level to smooth, broad areas between the streams the surface soil and subsurface layer will usually amount to about 12 inches. The upper subsoil of the type is a dark grayish-brown in color, becoming lighter at the lower depths. This layer extends to a depth of from 18 to 25 inches where it grades into a grayish-brown heavy silt loam to a depth of 25 to 35 inches. Below 35 inches the color is grayish-yellow or yellowish-brown and the soil material is soft and friable. Below this point there is the unweathered, unleached parent loess which consists of a loose, structureless grayish-yellow or yellowish-brown silt. In topography the Marshall silt loam is gently undulating to slightly rolling but in some places it is more hilly to rough. This soil is rather a

productive type and crop yields are very satisfactory. It is slightly acid in reaction in the surface soil and the addition of lime and phosphate fertilizers are recommended.

The Clarion loam is developed extensively in the Wisconsin drift soil area. The surface soil is a brown to very dark brown or black mellow, friable loam, 15 to 18 inches in depth. The subsoil is a yellowish-brown to grayish-brown friable clay loam, grading at 28 to 30 inches into a yellowish-gray or mottled gray, brown and yellow clay loam or clay. In the more level areas the soil is blacker in color due to the higher content of organic matter. In the lower subsoil in many places there are gray mottlings and occasionally there is a gray layer. This gray coloration of the subsoil is caused by the high content of lime which is characteristic of the Clarion soils. In topography the Clarion loam is gently undulating to rolling, and drainage in general is quite adequate. This soil is naturally a productive soil, has a medium nitrogen and organic matter content and responds to phosphate fertilizers.

The Clinton silt loam is found in the Mississippi loess soil area. The surface soil of the type is a grayish-brown or gray friable silt loam, 4 to

6 inches in depth. The subsoil is a mottled yellowish-brown and gray, tough, compact, silty clay loam extending to a depth of 24 to 30 inches. This compact subsoil is underlaid by a more friable silty clay loam material which becomes more silty at the lower depths. In topography the Clinton silt loam is hilly to rough and drainage is good to excessive. This soil is subject to serious erosion. It responds to applications of farm manure and lime and phosphate fertilizers are recommended.

The Carrington silt loam is found in the Iowan drift soil area. The surface soil of the Carrington silt loam consists of a grayish-brown, mellow loam, extending to a depth of 8 or 10 inches. The lower part of the surface layer is a very dark brown, finely granular, friable silt loam. The upper subsoil is a light brown or brown, heavy silt loam or silty clay loam, extending to a depth of 20 inches. Below that point and to a depth of 40 inches, the subsoil is a yellowish-brown clay loam containing faint grayish streaks. Below 40 inches the substratum or parent material consists of a grayish-yellow, gritty clay loam, containing coarse sand and small pebbles. In topography the Carrington silt loam varies from almost level to undulating. Drainage is generally quite adequate, but in the level

areas there is need for tiling. The natural fertility of this soil is high but beneficial results are secured from the application of farm manure, lime and phosphate fertilizers.

For convenience in designating the nine soils, numbers are used on the figures instead of the soil type names. These numbers were given to the various soils as shown in table II.

Methods and Results

All of the analyses were made by standard methods. Hillebrand's (38) methods for silica, iron and alumina were used, and these include the use of sodium carbonate fusion for silica. McCrudden's (50) methods for calcium was used, and this involves the precipitation of the calcium as calcium oxalate and titration with a standard solution of potassium permanganate. Harper's (36) modification of the phenol-disulfonic acid method was used to determine nitrates, and the total nitrogen of the soil was determined by the ordinary Kjeldahl method as described by Fred and Waksman (29). Truog's (77) 0.002 N. sulfuric acid method was employed for soluble phosphorus. The

TABLE II

SOILS USED IN SOME CHEMICAL AND PHYSICAL STUDIES

No.	Soil Types
1	Shelby loam
2	Webster silty clay loam
3	Tama silt loam
4	Grundy silt loam
5	Marshall silt loam
6	Clarion loam
7	Clinton silt loam
8	Carrington loam
9	Carrington silt loam

standard perchloric acid method for the determination of potassium and sodium was followed. Table III gives the results of this chemical analyses made on these nine Iowa soils.

The Webster soil lost 25.49 per cent of its weight on ignition, which was over twice as much as any of the other soils examined. The high organic matter content of this soil readily accounts for this loss. The color of these soils corresponds in general to the differences in the loss on ignition, the color being due chiefly to the organic matter present.

The SiO_2 content of these nine soils was found to be quite variable. As a general rule the drift soil had less SiO_2 than the finer loessial soils. The textural classes of the soils of these two divisions indicate that the silica content of the loessial soil would be higher than that of the drift soils. The SiO_2 content varied inversely with the loss on ignition, that is, where the loss on ignition was high the silica content was low.

The sesquioxides (Fe_2O_3 and Al_2O_3) were not determined separately. The Marshall silt loam contained the highest content of sesquioxides and the Shelby loam the lowest. The color of the Marshall silt loam might indicate a high alumina content due to its gray to grayish-

TABLE II

CHEMICAL ANALYSIS OF

Soil Types	Loss on ignition	SiO_2	R_2O_3	CaO	MgO	P
Shelby loam	8.92	70.52	15.62	0.79	0.10	
Webster silty clay loam	25.49	50.29	21.17	12.49	0.47	
Tama silt loam	9.87	70.30	18.81	1.00	0.78	
Grundy silt loam	8.12	69.12	20.95	0.79	0.46	
Marshall silt loam	11.31	55.20	27.80	1.04	2.27	
Clarion loam	9.67	69.27	17.97	1.00	1.90	
Clinton silt loam	11.12	67.60	17.93	0.85	1.81	
Carrington loam	10.27	66.44	18.34	0.62	0.93	
Carrington silt loam	8.30	61.82	19.00	1.12	1.21	

TABLE III

EMICAL ANALYSIS OF SOME IOWA SOILS

Percentage Composition											
$_2O_3$	CaO	MgO	P_2O_5	N	NO_3	K_2O	Na_2O	pH	% Colloid	Total Carbon	Inorganic Carbon
3.62	0.79	0.10	0.10	0.22	0.10	1.84	2.18	5.92	41.00	2.28	trace
1.17	12.49	0.47	0.18	0.34	0.15	1.65	2.47	8.16	45.60	7.33	1.03
8.81	1.00	0.78	0.13	0.22	0.05	2.46	1.87	5.55	40.60	2.72	trace
0.95	0.79	0.46	0.12	0.18	0.06	2.22	2.71	5.40	42.60	1.95	trace
7.80	1.04	2.27	0.15	0.26	0.05	1.70	2.24	6.14	39.60	2.92	trace
7.97	1.00	1.90	0.12	0.24	0.03	1.28	2.31	6.14	33.60	2.72	trace
7.93	0.83	1.81	0.13	0.22	0.04	2.00	2.50	5.77	39.60	2.74	trace
8.34	0.62	0.93	0.15	0.24	0.04	1.39	2.29	6.01	33.60	2.73	trace
9.00	1.12	1.21	0.15	0.19	0.04	1.82	2.54	5.88	38.00	2.16	trace

blue hue. The Webster silty clay loam was also high in sesquioxides. The high iron and alumina content in this soil might be associated with the high water table due to poor drainage. The Webster silty clay loam contained 12.49 per cent of calcium oxide which was approximately 12 times as much as was found in any other soil examined. This was the only soil that gave a pH above 7.0. A high calcium content is one of the important characteristics of a typical Webster soil as shown by the soil survey bulletins. The magnesium oxide content was quite variable, the Marshall, Clarion and Clinton soils containing the highest amounts.

The Webster silty clay loam contained the highest percentage of P_2O_5 and the Shelby loam was the lowest.

Table IV gives the data secured from the calculations of the $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ ratios.

The more fertile soils as indicated by crop yields, the Webster silty clay loam and the Marshall silt loam, exhibited a narrow ratio whereas the other soils all have a somewhat wider ratio. It would be difficult here to know how much difference in the ratio would be significant either as an indication of fertility

TABLE IV

SOLUBLE PHOSPHORUS, C:N RATIO AND $\frac{SiO_2}{R_2O_3}$ RATIO

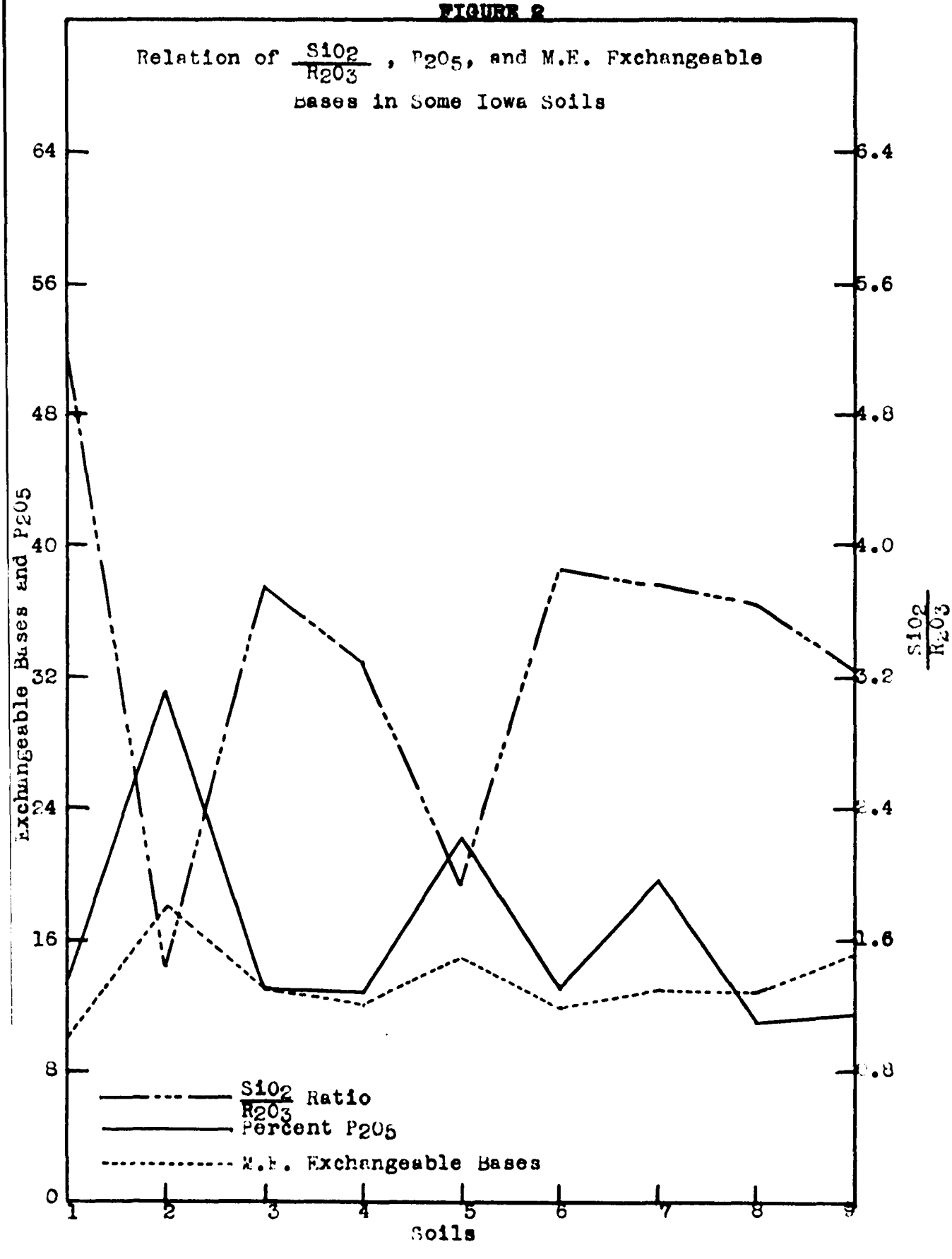
Soil Types	Composition		
	p.p.m. of 0.002N H_2SO_4 Soluble Phosphorus	C:N Ratio	$\frac{SiO_2}{R_2O_3}$ Ratio
Shelby loam	24	10.36	5.90
Webster silty clay loam	60	18.53	1.43
Tama silt loam	44	12.36	3.73
Grundy silt loam	76	10.83	3.29
Marshall silt loam	87	11.23	1.98
Clarion loam	51	11.33	3.85
Clinton silt loam	47	12.45	3.76
Carrington loam	33	11.37	3.62
Carrington silt loam	35	11.36	3.25

or as an aid in differentiating one soil type from another. Some investigators have said that soils having a $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ ratio of less than 2 tend to have a friable structure which will give rise to easy cultivation and general tillage practices. If the ratio is greater than 2 the soil is said to be more plastic and impervious which makes it more difficult to handle under general cultivation practices. Bradfield (12), Gile (31), and Anderson and Mattson (3) note the importance of the $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ ratio, and consider this fraction very important in all soil reactions.

Figure 2 shows the relationship between the $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ ratio and the per cent of P_2O_5. There is almost an inverse relation, that is, when the $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ ratio is wide the P_2O_5 content is low.

The nitrogen content of the Webster silty clay loam was relatively high and of the Grundy silt loam relatively low, the percentages being 0.34 per cent and 0.18 per cent, respectively. The nitrogen content of these soils followed the same general trend as the loss on ignition, that is, where the loss on ignition was high the total nitrogen was also high. The loss on ignition indicates roughly the amount of organic matter and the organic matter content of a soil is in general

FIGURE 2


Relation of $\frac{SiO_2}{R_2O_3}$, P_2O_5, and M.E. Exchangeable Bases in Some Iowa Soils
Exchangeable Bases and P2O5
$\frac{SiO_2}{R_2O_3}$
64
56
48
40
32
24
16
8
0
6.4
5.6
4.8
4.0
3.2
2.4
1.6
0.8
1
2
3
4
5
6
7
8
9
Soils
$\frac{SiO_2}{R_2O_3}$ Ratio
Percent P2O5
M.E. Exchangeable Bases

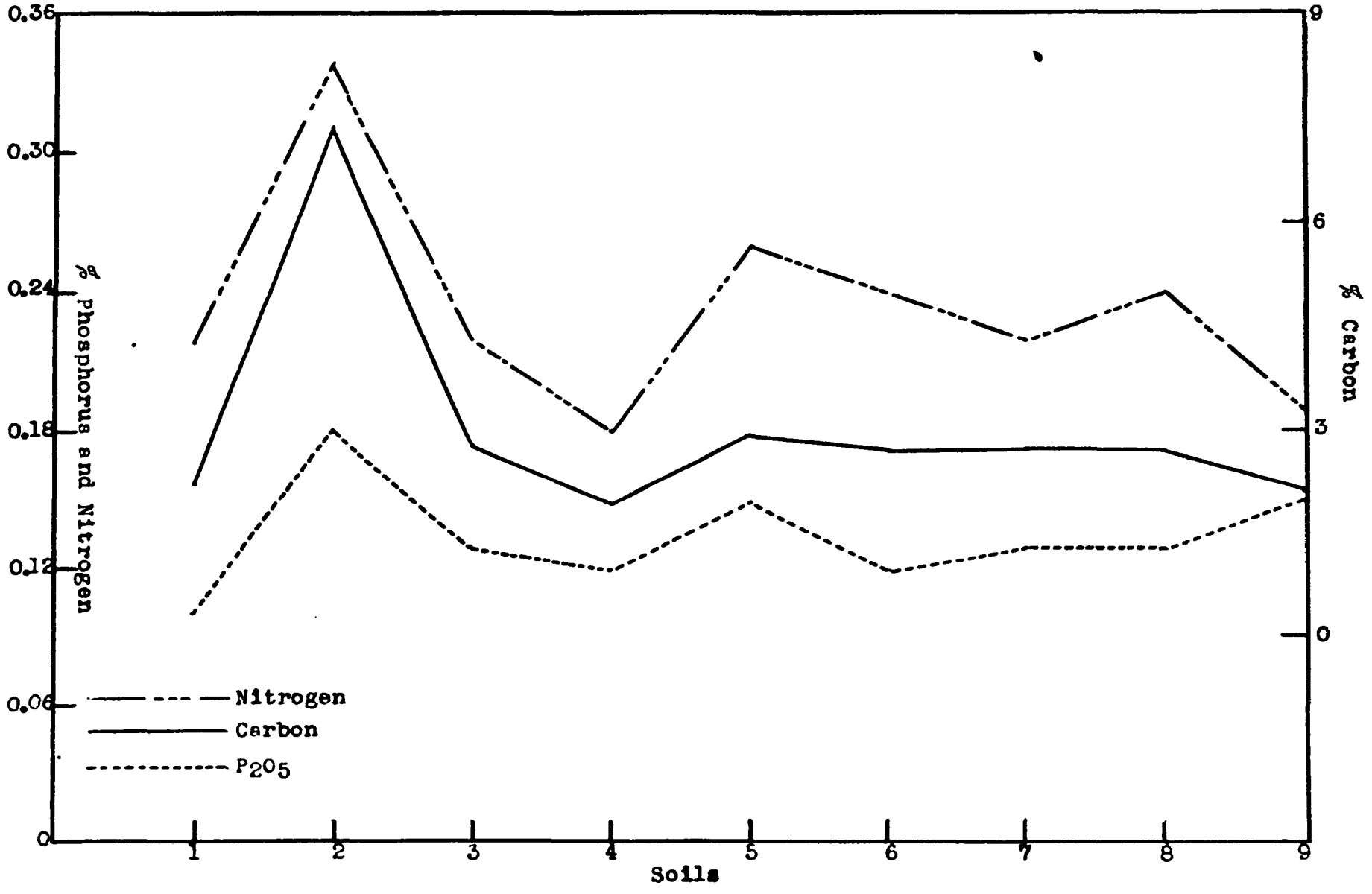
a fair indicator of the nitrogen supply.

The nitrate content of these soils was highest in the Webster silty clay loam and lowest in the Clarion loam. The K_2O content varied from 2.46 per cent in the Tama silt loam to 1.28 per cent in the Clarion loam, while the Na_2O content was highest in the Grundy silt loam and lowest in the Tama silt loam. The Tama silt loam was the only soil which had a higher K_2O content than Na_2O. The Webster silty clay loam was the only soil with a pH as high as 8.18, all of the other soils were acid, the Grundy silt loam being most acid and having a pH of 5.40. The Webster silty clay loam contained 45.60 per cent colloidal material while the Clarion loam and Carrington loam were the lowest, each containing 33.60 per cent. The Webster silty clay loam contained 7.33 per cent total carbon which was three times higher than the amount present in any of the other soils. The carbon and nitrogen varied directly with the loss on ignition.

The relationships of total carbon, nitrogen and phosphorus are shown graphically in figure 3. The carbon-nitrogen ratio was calculated and is shown in table IV. The Webster silty clay loam had the widest ratio and the Shelby loam had the lowest. The 0.002 N.

FIGURE 3

Relation of Nitrogen, Carbon, and Phosphorus in Some Iowa Soils



H_2SO_4-soluble phosphorus was determined and is shown in table IV. The soluble phosphorus apparently was not correlated with the total phosphorus present in the soil. Figure 4 shows the relation between SiO_2, R_2O_3, and the soluble phosphorus. The phosphorus content varied directly with the per cent R_2O_3 and inversely with the SiO_2.

The Webster silty clay loam contained 1.03 per cent of inorganic carbon and the amount of this element found in the other eight soils was so small that it was regarded as a trace.

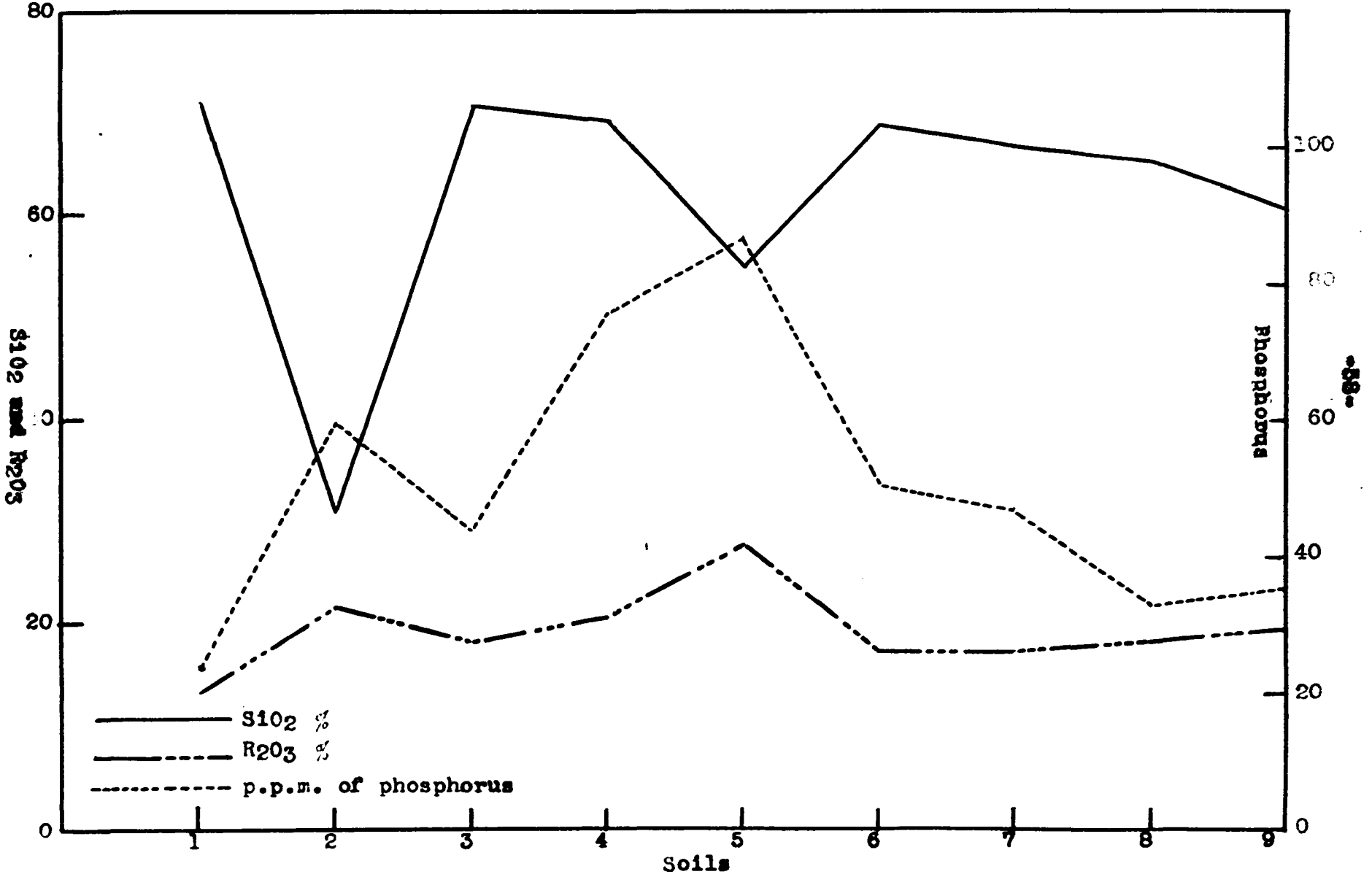
Robinson (61) analyzed a number of soils from the midwest and found that they differed widely in composition. His results agree very closely with those secured here.

Analyses of Soil Extracts

In the study of the soil extracts the same soils were used as in the preceding work. It was thought that the analyses of the soil extracts might show relationships between the extracts and the corresponding soils. Such correlations could be used as indicators of soil types.

FIGURE 4

Relation of Silica to the Sesquioxides and 0.002N H_2SO_4 Soluble Phosphorus in Some Iowa Soils



Methods and Results

Various methods for obtaining the soil solution were tested, including a modification of the method used by Briggs and McCall (14) in 1904. These investigators used a porous porcelain tube buried in the soil and connected to a flask which had been partially evacuated under a vacuum pump. The modification used in this work consisted in a Pasteur-Chamberlain filter buried in the soil and connected by means of heavy-walled pressure tubing to the intake suction line of a six-cylinder automobile engine. It was found that the vacuum produced by the engine was much greater than could be obtained from a flask partially evacuated. Appreciable quantities of the soil solution could be obtained only when the soil had a moisture content of 20 per cent or more. The solution obtained in this manner was of doubtful value because of the absorption of phosphorus by the filter. Another objection to the method was that the solution obtained was probably only the excess moisture found in the soil, which upon analysis was found to contain negligible quantities of minerals. This method was finally discarded in favor of the 1:5 water extract method proposed by Hoagland, Martin and Stewart (39) in 1920. They recommended placing the soil in water

in a flask and shaking for two to three hours, after which time the mixture was allowed to stand for one week then filtered. In this work 100 gram samples of air dried soil were placed in quart milk bottles and 500 cc. of distilled water added to each. This mixture was placed in an end-over-end shaking machine and run for 3 hours, then let stand for one week to allow for equilibrium to be established after which the supernatant liquid was siphoned off and filtered. In filtering these solutions some difficulties were encountered. The solution when filtered through an ordinary filter paper did not come through clear. It was then filtered through an asbestos mat prepared on a Büchner funnel but this also failed to yield a clear extract. Pasteur-Chamberlain filters gave a clear solution, but due to the absorption of some ions by the filter this method of filtration was discarded. Collodion sacks were tried and found to give a clear extract but this method was too time consuming. Finally, the mixture was filtered through Jena-glass filters. These filters yielded a clear solution from some of the soil-water mixtures, but for others it was opaque. For the latter soil-water mixtures it was necessary to place a filter pad composed of finely mascerated and

washed filter paper on top of the Jena-glass filters to get a clear extract. The suggestion for the uniformity of data in soil solution analyses as outlined by Bollen and Neidig (8) employed the use of milligram-equivalents of elements per liter. This was not used in the following analysis because the preceding analyses of soils were based on percentage. It was desired to compare the analytical data from both the soil and soil extract studies, therefore, the percentage of constituents was used throughout this work. Table V gives the analysis of the 1:5 water extracts prepared from the nine Iowa soils used throughout this work.

The SiO_2 content of the extracts from these soils was very small and in the case of the Webster soil no SiO_2 was found.

The Webster silty clay loam contained the lowest sesquioxide content whereas the Clarion loam and Tama silt loam were highest in this constituent. No relation seemed to exist between the amount of SiO_2 and R_2O_3 extracted in the water and the total amount of these constituents found in the soil.

The Webster silty clay loam which was highest in total calcium did not contain the most water soluble calcium. The Carrington loam contained 0.51 per cent

TABLE V

ANALYSIS OF SOME IOWA SOIL EXTRACTS

Soil Types	Percentage Composition								
	SiO_2	R_2O_3	CaO	MgO	P_2O_5	NO_3	K_2O	Na_2O	pH
Shelby loam	0.10	0.14	0.28	0.09	0.00	0.08	0.01	0.07	5.82
Webster silty clay loam	0.00	0.03	0.33	0.30	trace	0.13	0.01+	0.10	7.21
Tama silt loam	0.09	0.40	0.31	0.25	0.00	0.05	0.01+	0.04+	6.48
Grundy silt loam	0.04	0.21	0.34	0.11	0.00	0.06	0.01-	0.04-	5.26
Marshall silt loam	0.09	0.25	0.37	0.14	trace	0.03	0.01-	0.04-	6.48
Clarion loam	0.12	0.42	0.36	0.14	0.00	0.03	0.01-	0.04-	6.59
Clinton silt loam	0.22	0.13	0.46	0.26	0.00	0.04	0.02-	0.03	6.34
Carrington loam	0.01	0.20	0.51	0.13	0.00	0.02	0.02+	0.03+	6.83
Carrington silt loam	0.03	0.06	0.33	0.25	trace	0.03	0.01+	0.03-	7.01

calcium in the water extract which was almost as much calcium as was found in the soil. The Shelby loam contained the lowest amount of calcium in the water extract.

The Webster silty clay loam contained the highest content of MgO and the Shelby loam the lowest.

The Webster silty clay loam, the Marshall silt loam and the Carrington silt loam contained only a trace of P_2O_5 in the 1:5 water extract. All of the other soils failed to give any indications of the presence of water soluble phosphorus. The nitrate determination made on these water extracts failed to give the same results as were secured when the nitrates were determined on the soils. This might be explained by the fact that these soils were shaken with water for three hours and left to stand for one week during which time conditions might have been favorable for denitrification.

The K_2O content of these extracts was very low, ranging from 0.01- per cent to 0.02+ per cent. The sodium content was considerably higher than that of potassium, ranging from 0.03- to 0.10 per cent.

The pH of the extract of the Webster silty clay loam was 7.21 which was considerably lower than the pH of the soil. The water extract of the Carrington

silt loam gave a pH of 7.01 which was higher than the pH of the soil. Why an acid soil should give a water extract with a higher pH than the soil itself cannot be satisfactorily explained at this time. The extracts of all of the other soils were acid in reaction.

Effect of Varying Soil-Water Ratio on the Amount of Soluble Salt Extracted

Many investigators have reported on the amount of soluble salts dissolved out of soils by different soil-water ratios. It has been said that all water extracts of soils contained more soluble minerals than the true soil solution as found in the soil. This work was carried out to determine the relation between the amount of soluble salt dissolved and the ratio of soil to water.

Table VI shows the amount of soluble salts extracted by various dilutions of water from these soils. The dilutions were 1:5, 1:10, 1:20, 1:40 and 1:80. The soil and water mixtures were shaken for three hours and allowed to stand for one week, after which they were filtered. Fifty cc. portions from each of these clear extracts, sampled in duplicate, were placed in tared porcelain crucibles, evaporated, cooled and weighed. The water-soluble salt contents per 100 grams

TABLE VI

SOLUBLE SALTS EXTRACTED BY VARIOUS DILUTIONS OF WATER FROM SOME IOWA SOILS

Soil Types	Grams per 100 gm. of soil				
	1:5	1:10	1:20	1:40	1:80
Shelby loam	0.067	0.104	0.140	0.240	0.368
Webster silty clay loam	0.116	0.181	0.260	0.404	0.624
Tama silt loam	0.057	0.086	0.101	0.160	0.208
Grundy silt loam	0.050	0.066	0.084	0.080	0.080
Marshall silt loam	0.089	0.108	0.188	0.280	0.432
Clarion loam	0.069	0.106	0.160	0.216	0.352
Clinton silt loam	0.071	0.120	0.152	0.208	0.384
Carrington loam	0.097	0.132	0.176	0.304	0.432
Carrington silt loam	0.047	0.064	0.084	0.064	0.064

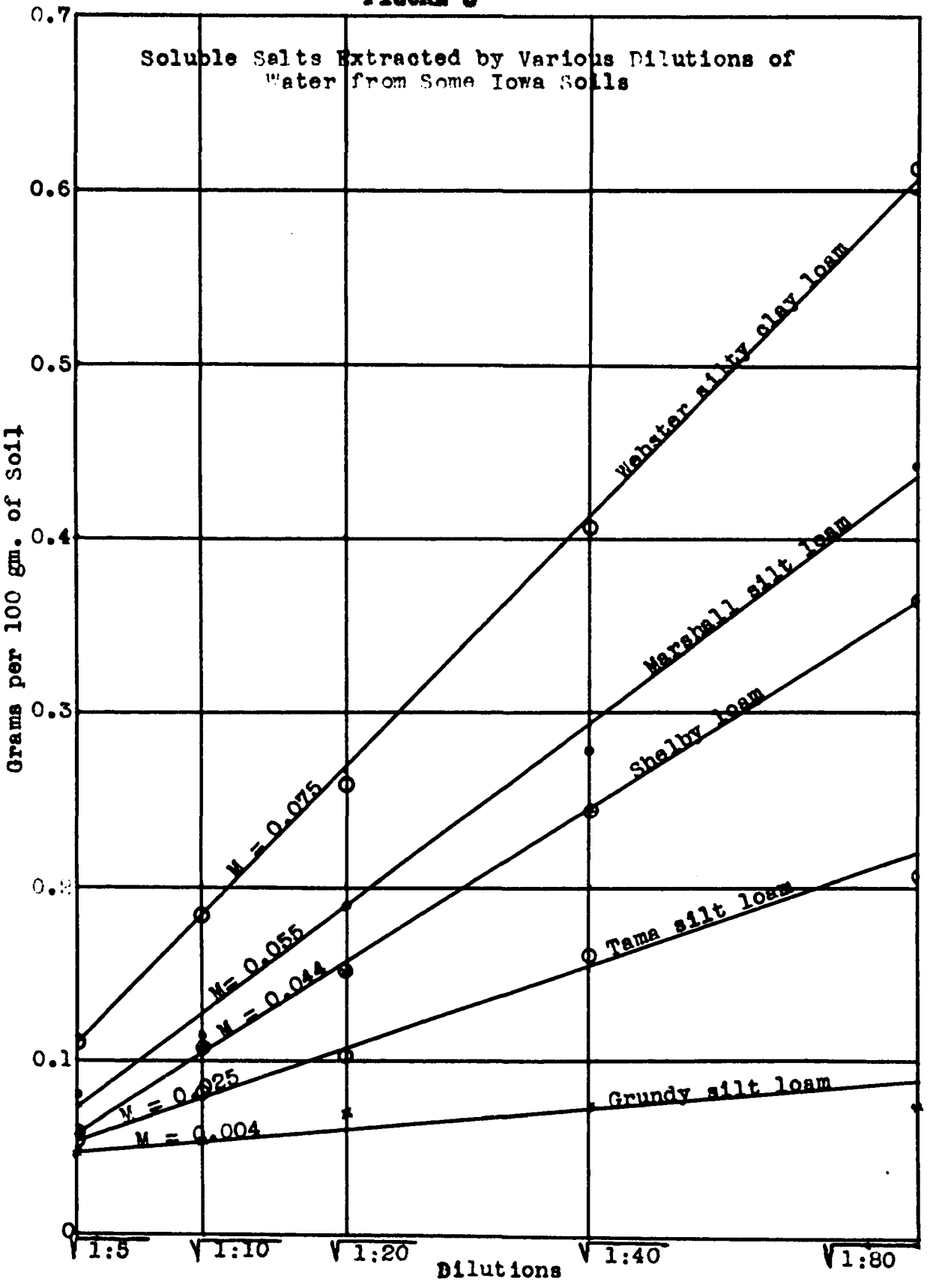
of soil were calculated. The soluble salt content increased in all soils from the 1:5 water extract through the 1:20 water extract. In the higher dilutions all of the soil extracts showed higher soluble salt content except the Grundy silt loam and the Carrington silt loam which decreased in the 1:40 and the 1:80 water extracts. The results are shown graphically in figure 5.

The square root of the ratio of volume of solution to weight of soil was plotted against the amount of soluble salts extracted and it was found possible to connect these points for the five dilutions for each soil by a straight line. The slope (M) of the line was determined. The magnitude of the slope of the line for the different soils was highest for the Webster silty clay loam and next in descending order were Marshall, Shelby, Tama and Grundy. These data indicate that each soil has a characteristic solubility of salts, and in this case the solubilities were all different.

Conductivity of Soil Extracts

Electrical conductivity measurements were made on the 1:5 water extracts from each of the nine soils to determine what relationships if any existed between the conductivity of the extracts and the total salt content, as shown in the analyses of the soil extracts.

FIGURE 5


Soluble Salts Extracted by Various Dilutions of Water from Some Iowa Soils
Grams per 100 gm. of Soil
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Webster silty clay loam
Marshall silt loam
Shelby loam
Tama silt loam
Grundy silt loam
M = 0.075
M = 0.055
M = 0.044
M = 0.025
M = 0.004
1:5
1:10
1:20
1:40
1:80
Dilutions

Findlay's (28) outline of conductivity measurements for the various solutions was used in determining the specific conductivity of the various soil extracts. The specific conductivity of these 1:5 water extracts was determined and the results are shown in table VII.

The conductivity of the Carrington loam extract was highest and that of the Marshall silt loam the lowest. The data secured in this table do not show a correlation existing between the conductivity measurements of the soil extract and the water soluble salt content as determined by chemical analysis.

Discussion

These physical and chemical studies of soils have given data which indicate that each of the soils and their water extracts may be characterized by composition. The $\frac{SiO_2}{R_2O_3}$ ratio, and the C:N ratio varies for each of the soils and if properly interpreted, and based on sufficient analyses, might give indications of soil type. However, the analysis of only one sample of each of these soils is not sufficient to give conclusions as to soil type. If it was sufficient then when a soil analysis showed it to have very nearly the same quantities of the

TABLE VII

SPECIFIC CONDUCTIVITY OF SOME IOWA SOIL EXTRACTS

Soil Types	Mhos
Shelby loam	8.05×10^{-5}
Webster silty clay loam	2.55×10^{-5}
Tama silt loam	1.40×10^{-5}
Grundy silt loam	7.82×10^{-6}
Marshall silt loam	9.42×10^{-6}
Clarion loam	1.46×10^{-5}
Clinton silt loam	8.54×10^{-6}
Carrington loam	1.26×10^{-5}
Carrington silt loam	2.16×10^{-5}

same constituents as one of these soils, it could be called the same soil type. Of course, the history of the soil, the formation, the geological characteristics, the treatment and the like should be known and considered in the classification.

The four soils studied in the preliminary work showed that most of the organic matter (excluding undecomposed organic matter which could be screened out) was colloidal in nature. The total colloidal content of these soils varied from 20.60 to 45.60 per cent. In most of the soils from 0.1 to 0.05 of the colloids present were organic.

The analysis of the soils and their water extracts did not show any very definite characteristics common to both. The K_2O content of these soils indicated that all of the soils had an ample supply, however, additions of KCl might be beneficial. This would depend on the way the potassium is held in the soil and on the needs of the crop. The Na_2O content was higher than the potassium, and was thought to be sufficient for soil reactions and plant food supply. The organic matter and nitrogen were high in the Webster silty clay loam soil, as would be expected from the characteristics of the Webster soil. Electrical conductivity measurements of

the various water extracts did not show a direct correlation between water soluble salts and the conductivity. Varying amounts of salts were extracted from soils by varying the ratio of soil to water. In most cases when the soil:water ratio was wide the most salts were found to come into solution.

BASE EXCHANGE RELATIONSHIPS

The exchangeable bases of each of these soils were determined to find what relationship if any exists between the exchange constituents, the water soluble constituents, and the total soil constituents. It seemed desirable to determine to what extent the salts dissolved out by the 1:5 water extract represent the exchangeable bases and also if the exchangeable hydrogen is indicated by the pH of the soils or the soil extracts. For many years it has been assumed that there is a relation between colloids, silica, iron, and alumina content and the base exchange properties of soils. Kerr (47) and McGeorge (51, 52) found definite relationships existing between the organic carbon content of soils and their exchange capacity. Their work showed that the organic fraction of the soil is one of the most important to be considered in base exchange reactions. It was also shown that the replacement capacity for bases in soils increased with the successive

stages of decomposition of organic matter present.

Methods and Results

Prianischnikow (61) in 1913 used a two-molar solution of ammonium acetate for the estimation of exchangeable potassium in soils. He considered this the most satisfactory salt for the purpose, especially because it was easily decomposed by evaporation upon a steam bath leaving only a slight residue of acetamide which might be volatilized at a slightly higher temperature or destroyed by digestion with aqua regia.

Later, Bray and Wilhite (13) suggested that the total replaceable bases of a soil could be determined by titrating the carbonates or oxides formed after heating the ammonium acetate solution which had been leached through the soil. Chapman and Kelley (25) experienced difficulties in determining replaceable calcium in calcareous soils. They obtained the best results when a sodium chloride solution was used as the leaching agent in calcareous soils. Kelley (44) estimated that from 75 to 90 per cent of the replaceable bases are calcium, about 10 to 15 per cent magnesium and only a small per cent, potassium and sodium. Schollenberger (69) reported on the advantages of ammonium acetate over ammonium chloride and barium chloride in base exchange studies. Ammonium acetate is a "neutral" salt

and is a good buffer when the reaction is around the neutral point. He suggested that a normal solution of ammonium acetate at a pH of 7.0 is a good solvent for all the bases which might be important in soil work.

Later, Schollenberger and Dreibelbis (71) proposed the ammonium acetate method for leaching and determining the exchangeable bases in soils. This method was followed in the work carried on in this experiment. Difficulties were encountered in the determination of exchangeable calcium in the Webster silty clay loam. Much too high a content of exchangeable calcium was secured when compared with the total exchange capacity of the soil. Hence, a suggestion given by Kelley and Brown (46) was followed. This involved a second leaching of the soil by a neutral solution of ammonium acetate adjusted to a pH of 7.0, subtracting the calcium found in both solutions, and the difference was assumed to be the exchangeable calcium. This procedure proved satisfactory.

The total exchange capacity of the soils was measured by leaching the soil with ammonium acetate solution, then with alcohol to remove any excess of ammonia which might be present. The soil was then transferred to Kjeldahl flasks, calcium oxide and 250 cc. of distilled water were added. This was boiled and the distillate collected in a

known amount of standard acid, which was titrated with standard alkali and the milligram-equivalents of the exchange capacity calculated.

The exchangeable hydrogen was determined by an electrometric titration method. The pH was determined on the leachate from the soil and known amounts of a standard solution of ammonium hydroxide were added and stirred by means of a motor with the pH reading being taken after each addition until the pH was greater than 7.0. The pH values obtained after the addition of the various amounts of the ammonium hydroxide solution were plotted on a graph against the cc. of ammonium hydroxide and from the point where the pH of the leachate crossed the pH of the original leaching solution, the exchangeable hydrogen was calculated. The results obtained are given in table VIII.

The exchange capacity of the soil, the exchangeable hydrogen, exchangeable bases, per cent saturation of bases, potassium, calcium, and sodium were determined on each soil. All of the results are expressed in milligram-equivalents per 100 grams of soil.

The exchange capacity of the Webster silty clay loam was 34.3 milligram-equivalents whereas the Marshall silt loam had an exchange capacity of 28.8 milligram-equivalents, the Clinton silt loam 27.0, and the Carrington loam was lowest with 18.1 milligram-equivalents.

TABLE VIII

EXCHANGEABLE BASES IN SOME IOWA SOILS

Soil Types	M.E. per 100 gram of soil						
	Exchange Capacity	Exchangeable Hydrogen	Exchangeable Bases	Potassium	Calcium	Sodium	Percent Saturation of Bases
Shelby loam	20.90	6.83	14.07	0.66	10.01	4.46	67.32
Webster silty clay loam	34.30	3.06	31.24	1.33	26.44	3.07	91.08
Tama silt loam	20.40	6.73	13.67	1.33	10.00	2.79	67.00
Grundy silt loam	19.90	6.93	12.97	1.21	9.96	2.34	65.18
Marshall silt loam	28.80	6.53	22.27	1.26	17.41	4.50	77.32
Clarion loam	18.50	5.63	12.87	0.71	11.02	2.35	69.56
Clinton silt loam	27.00	7.32	19.68	0.66	14.43	4.91	73.29
Carrington loam	18.10	6.93	11.17	0.64	7.48	3.70	61.71
Carrington silt loam	18.60	7.00	11.60	0.67	7.94	3.50	62.36

It has been reported that the organic matter content and the exchange capacity of soils are closely related. This was found to be the case in this work as shown in figure 6. The loss on ignition very nearly paralleled the exchange capacity. The carbon-nitrogen ratio varied the same as the loss on ignition and the exchange capacity but this ratio did not vary as much for the different soils as did the loss on ignition and the exchange capacity.

The Webster silty clay loam contained the smallest amount of exchangeable hydrogen and the Clinton silt loam the largest amount, 3.06 and 7.32 M.E., respectively. The relationships existing between the pH of the soils and soil extracts to the exchangeable hydrogen in the soils are shown in figure 7. It will be noted that the pH of the soils and of the soil extracts varied almost directly, that is, the lines almost paralleled one another. The milligram-equivalents of exchangeable hydrogen plotted on the same figure shows an inverse relationship. Where the exchangeable hydrogen is high the pH values tend to be low, however, this is to be expected because with an acid reaction there should be the most exchangeable hydrogen.

The exchangeable bases in the soils were calculated from the total exchange capacity and the exchangeable hydrogen. The exchangeable bases were found to be highest

FIGURE 6

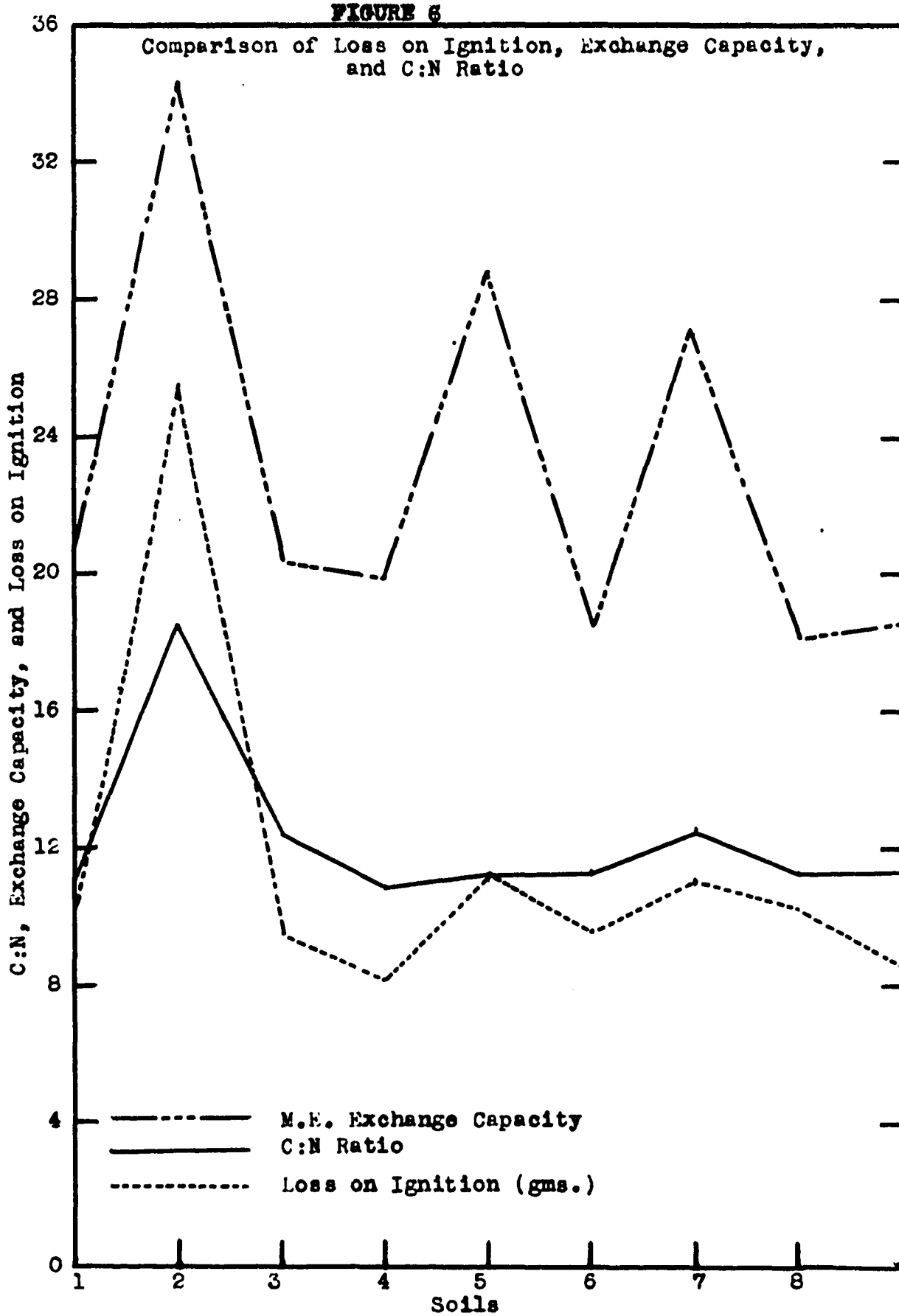
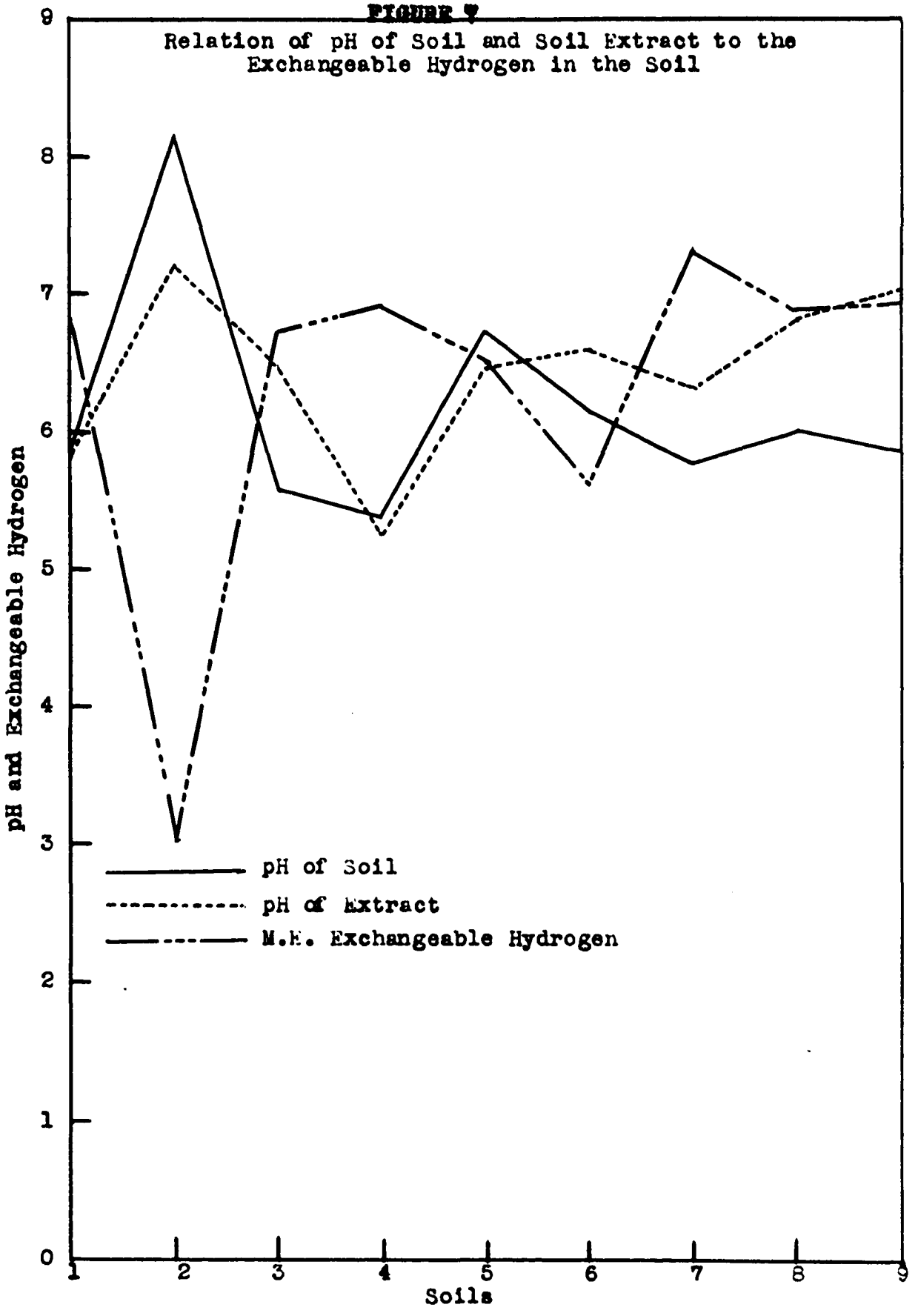

Comparison of Loss on Ignition, Exchange Capacity, and C:N Ratio
C:N, Exchange Capacity, and Loss on Ignition
36
32
28
24
20
16
12
8
4
0
1
2
3
4
5
6
7
8
9
Soils
M.E. Exchange Capacity
C:N Ratio
Loss on Ignition (gms.)

FIGURE V

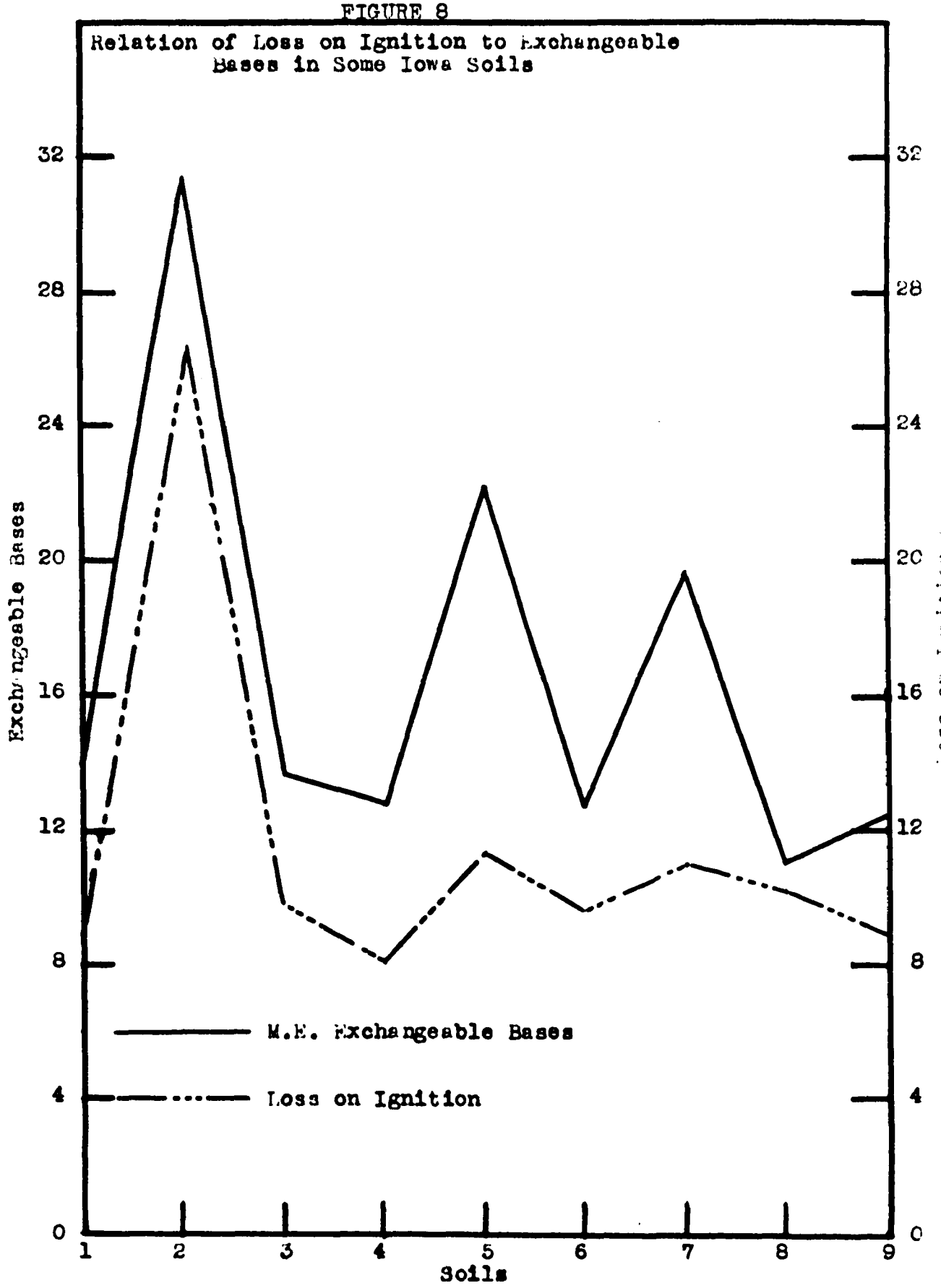
Relation of pH of Soil and Soil Extract to the Exchangeable Hydrogen in the Soil



in the Webster silty clay loam, 31.42 milligram-equivalents, Marshall silt loam was next with 22.27, and Carrington loam had the least with 11.07 milligram-equivalents. If the organic matter is as important in base exchange reaction as has been claimed, then the milligram-equivalent of exchangeable bases should show some correlation with loss on ignition determinations. This comparison was made and is shown on figure 8. The loss on ignition and exchangeable bases paralleled one another very closely. In both of these determinations three of the nine soils studied stood out as being high. They are the Webster silty clay loam, the Marshall silt loam and the Clinton silt loam. Agriculturally, all three of these soils are productive.

The potassium content of the soils varied considerably with the Webster, Tama, Grundy and Marshall soils having over 1.2 milligram-equivalents of exchangeable potassium. The other five soils ranged from 0.64 milligram-equivalents to 0.71 milligram-equivalents of exchangeable potassium. All of the soils yielded enough exchangeable potassium to supply plant food needs. However, beneficial results have been secured on some of these soils from muriate of potash treatments. Why this is so with this high available or exchangeable content of potassium,

FIGURE 8


Relation of Loss on Ignition to Exchangeable Bases in Some Iowa Soils
Exchangeable Bases
32
28
24
20
16
12
8
4
0
M.E. Exchangeable Bases
Loss on Ignition
1
2
3
4
5
6
7
8
9
Soils

cannot be said. It was thought that there might be some correlation between the milligram-equivalents of exchangeable potassium, the per cent potassium in the soils, and the per cent potassium in the water extracts. Due to the fact that all of these base exchange determinations show the elements and not the oxides of the elements as are shown in the chemical analysis of the soils and their water extracts, the oxides were recalculated on the basis of the elements and are shown in table IX as the per cent of potassium, sodium and calcium and the milligram-equivalents of these three elements.

The relationships of the calcium in the soils and in the soil extracts to the exchangeable calcium in the soils are shown in figure 9. The only similarity in regard to these three calcium determinations is found in the Webster silty clay loam where the calcium tends to be high in every case. Figure 10 shows the relations existing between the total potassium in the soils and in the soil extracts to the exchangeable potassium. In this case no correlations were observed.

The relation of total sodium in the soils and soil extracts to the exchangeable sodium are shown in figure 11. Again no correlations were observed between the sodium in the soil or in the soil extract

TABLE IX

THE POTASSIUM, SODIUM AND CALCIUM CONTENT OF

Soil Types	M. E. Exchange Potassium	Per cent Potassium in Extract	Per cent Potassium in the Soil	M. E. Excha Sodiu
Shelby loam	0.66	0.0083	1.53	4.4
Webster silty clay loam	1.33	0.0083	1.37	3.0
Tama silt loam	1.33	0.0083	2.04	2.7
Grundy silt loam	1.21	0.0083	1.84	2.3
Marshall silt loam	1.26	0.0083	1.41	4.5
Clarion loam	0.71	0.0083	1.06	2.3
Clinton silt loam	0.66	0.0166	1.66	4.9
Carrington loam	0.64	0.0166	1.16	3.7
Carrington silt loam	0.67	0.0083	1.51	3.5

TABLE IX

D CALCIUM CONTENT OF SOME IOWA SOILS

nt ium ract	Per cent Potassium in the Soil	M. E. Exchange Sodium	Per cent Sodium in Extract	Per cent sodium in the Soil	M. E. Exchange Calcium	Per cent Calcium in Extract	Per cent Calcium in the Soil
83	1.53	4.46	0.052	1.62	10.01	0.200	0.564
83	1.37	3.07	0.074	1.82	26.44	0.238	8.918
83	2.04	2.79	0.030	1.39	10.00	0.221	0.714
83	1.84	2.34	0.029	2.01	9.96	0.243	0.564
83	1.41	4.50	0.029	1.66	17.41	0.264	0.743
83	1.06	2.35	0.029	1.71	11.01	0.257	0.714
.66	1.66	4.91	0.022	2.25	14.43	0.358	0.593
.66	1.16	3.70	0.022	1.70	7.48	0.364	0.443
83	1.51	3.50	0.022	1.88	7.94	0.236	0.799

FIGURE 9
Relation of Total Calcium in the Soil and Soil Extract to the Exchangeable Calcium

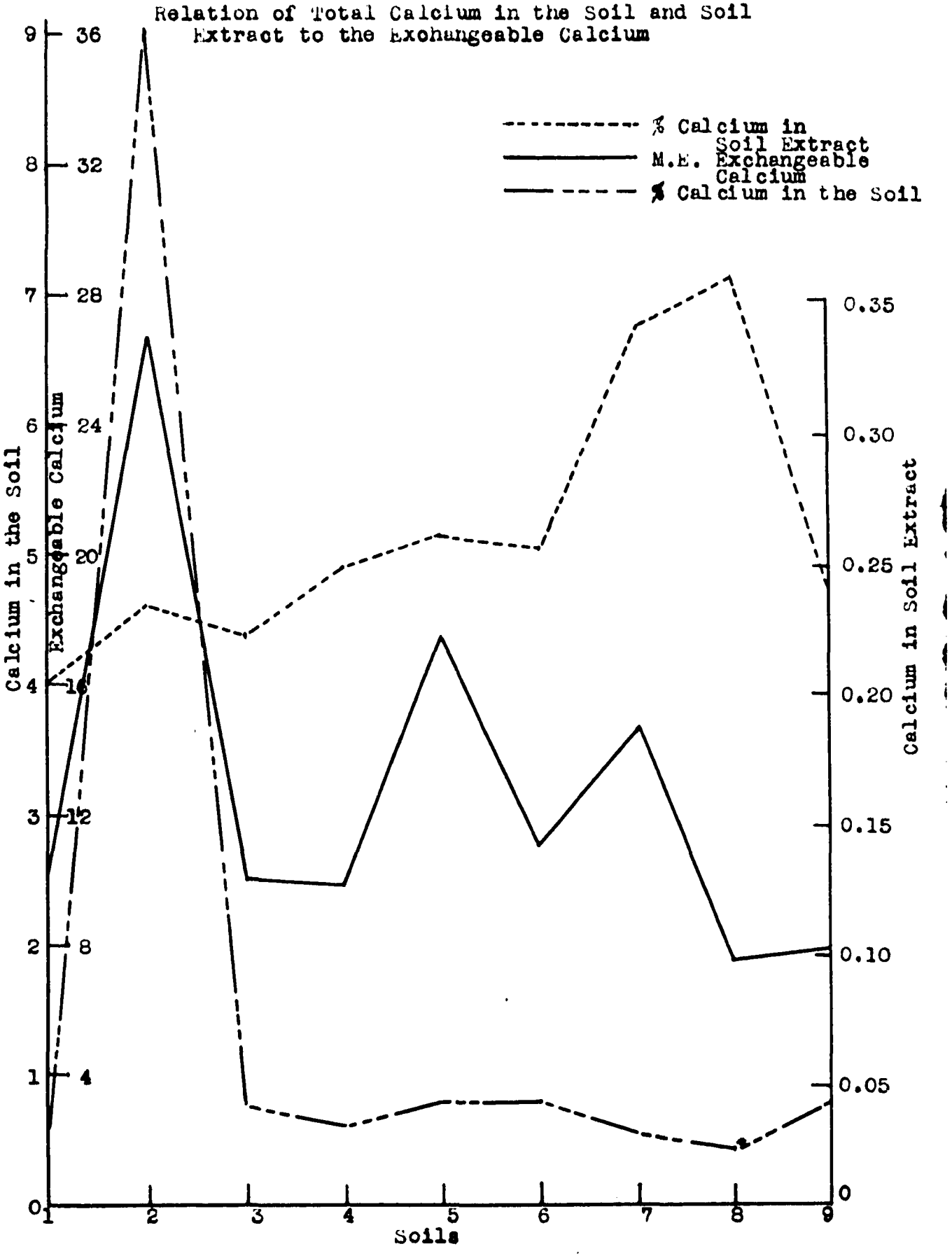


FIGURE 10

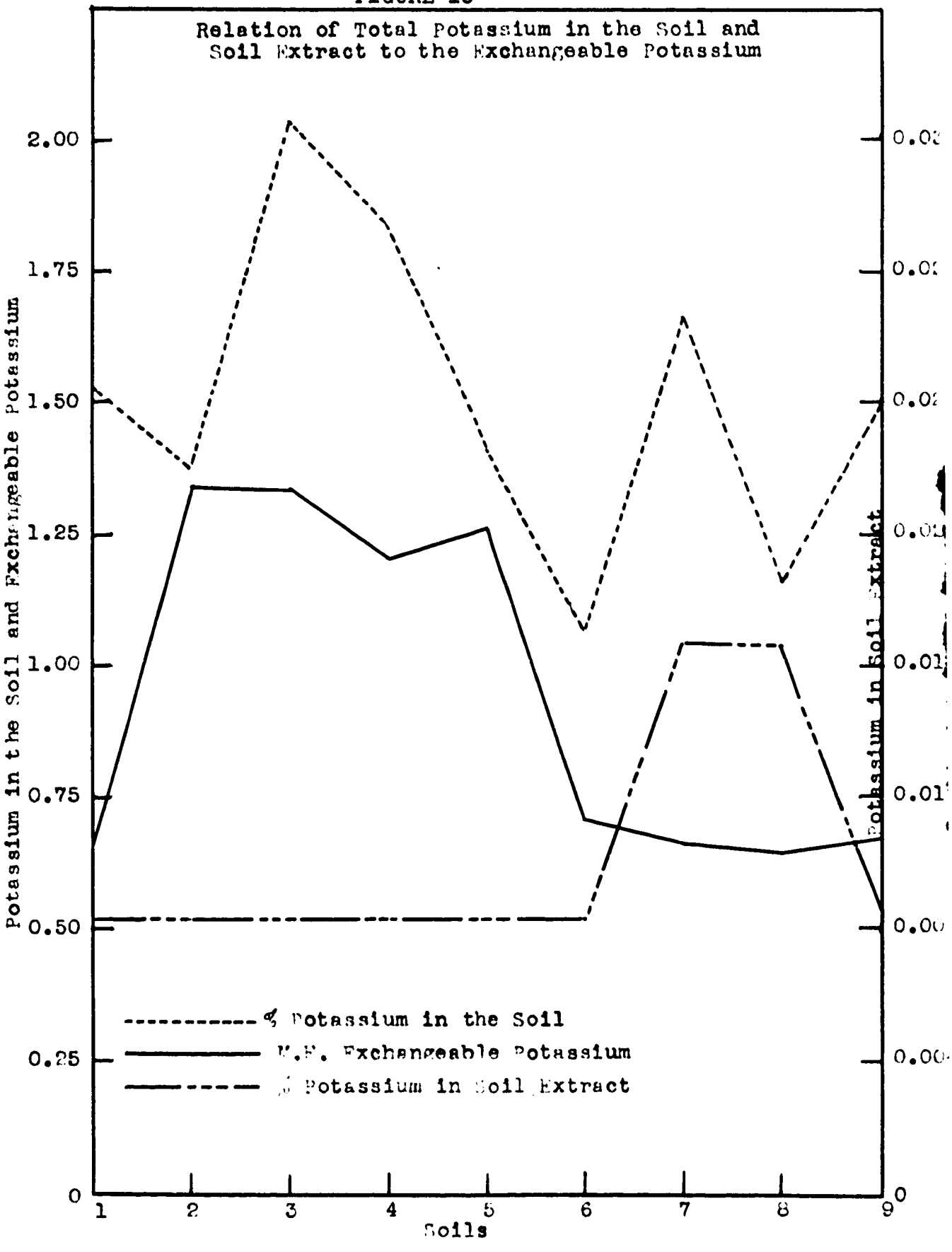
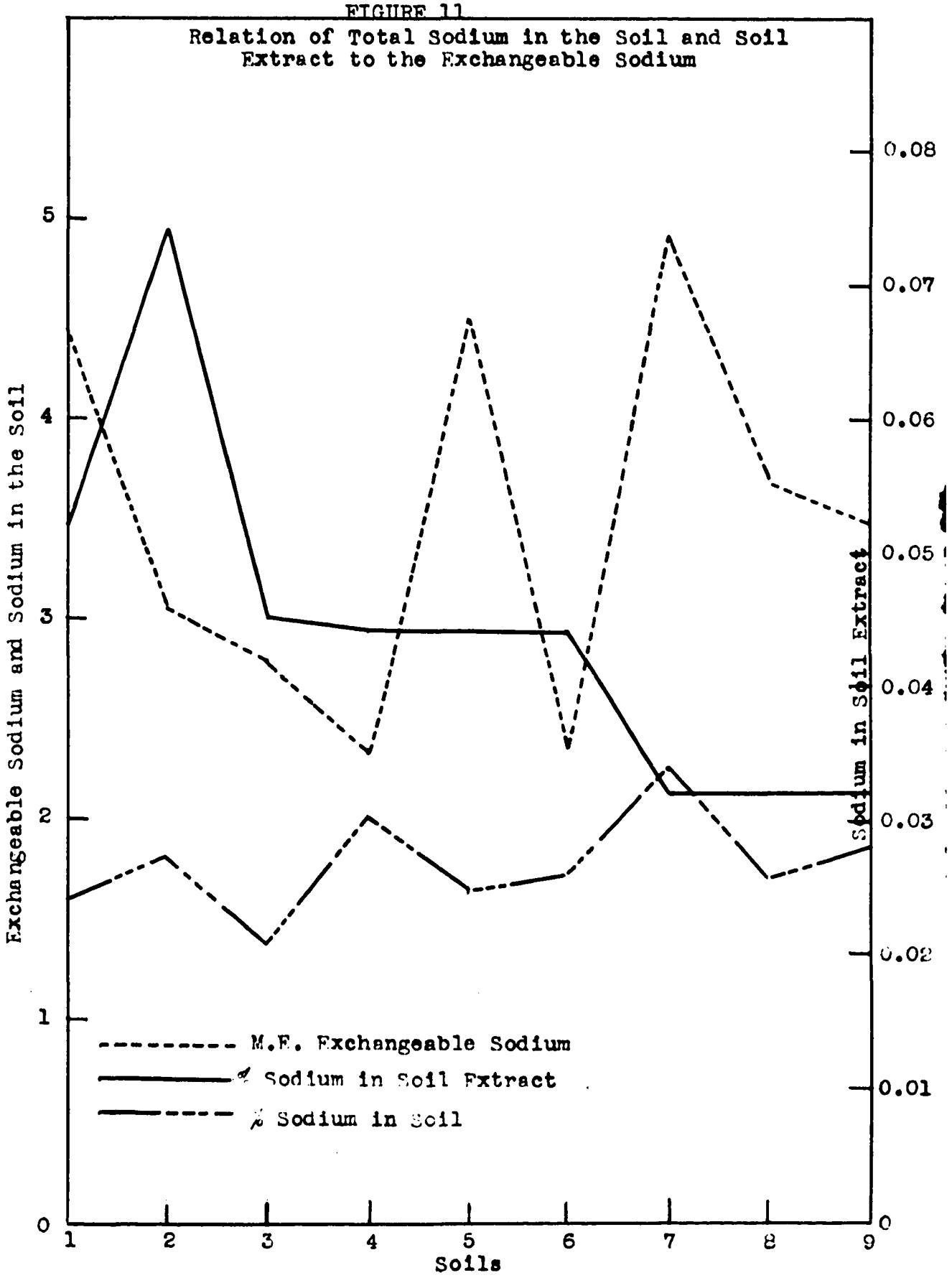

Relation of Total Potassium in the Soil and Soil Extract to the Exchangeable Potassium
Potassium in the Soil and Exchangeable Potassium
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0
1
2
3
4
5
6
7
8
9
Soils
% Potassium in the Soil
M.E. Exchangeable Potassium
% Potassium in Soil Extract

FIGURE 11

Relation of Total Sodium in the Soil and Soil Extract to the Exchangeable Sodium



and the exchangeable sodium in the soil.

Apparently there was no relation between the calcium, potassium and sodium as extracted from the soil in the 1:5 water extract, the exchange calcium, potassium and sodium and the total calcium, potassium and sodium in the soils studied.

Discussion

The exchange properties of nine Iowa soils were studied to determine what differences might be attributed to each individual soil type. The total exchange capacity, exchangeable hydrogen, exchangeable bases, such as calcium, potassium and sodium were determined on these nine soils.

1. The Webster silty clay loam had the greatest exchange capacity, and also the greatest exchangeable base content, both apparently having some relation to the organic matter present in the soil.

2. All of the soils showed a relatively high content of exchangeable calcium, with the Webster silty clay loam considerably higher than any of the others.

3. The exchangeable potassium and sodium was high in all nine of the soils.

4. In general there were no apparent differences peculiar to any particular soil type, except the Webster silty clay loam, which gave strikingly higher results in most of the exchange reactions.

BACTERIOLOGICAL IMPORTANCE OF THE SOIL SOLUTION AND COLLOIDS

Methods and Results

Very little work of any importance has been done to show the effect of the soil colloids or the soil solution on the growth of microorganisms. It was considered probable at the beginning of this work that the soil colloids might act as the natural habitat for both the aerobic and anaerobic organisms found in the soil. If such were the case, the soil solution might provide nutrients for the organisms. In some preliminary studies colloidal material was separated from the Webster silty clay loam soil, kept moist and used in different cultural media on which the following organisms were grown: Rhizobium leguminosarum, Bacillus radiobacter, and Azotobacter chroococcum. The various media and their composition are shown in table XII.

Mixed cultures of anaerobic organisms were isolated from the Webster silty clay loam and grown in mixtures of colloids plus dextrose, soil plus dextrose, sterile colloids plus dextrose, sterile soil plus dextrose, sterile soil and sterile colloids. Growth was measured by gas production and this was determined by the Barcroft differential manometer.

TABLE XII

MEDIA USED IN GROWING CULTURES

MEDIUM 1A

Rhizobium leguminosarum
and
Bacillus radiobacter

Agar.	15.0 gm.
Colloid (Soil).	2.0 gm.
K_2HPO_4.	0.5 gm.
$MgSO_4.7H_2O$.	0.2 gm.
NaCl.	0.1 gm.
$CaCO_3$	3.0 gm.
Yeast water (pH 6.8).	100.0 cc.
Distilled water	900.0 cc.

MEDIUM 2A

Rhizobium leguminosarum
and
Bacillus radiobacter

Medium 1A	1000.0 cc.
Mannitol.	10.0 gm.

MEDIUM 1

Azotobacter chroococcum

Agar.	15.0 gm.
Colloid (Soil).	2.0 gm.
K_2HPO_4.	0.5 gm.
$MgSO_4.7H_2O$.	0.2 gm.

TABLE XII (Cont.)

NaCl.	0.2 gm.
$MnSO_4.4H_2O$.	trace
$FeCl_3.6H_2O$.	trace
Distilled water	1000.0 cc.

MEDIUM 2

Azotobacter chroococcum

Medium 1	1000.0 cc.
Mannitol	10.0 gm.

MEDIUM 3

Rhizobium leguminosarum
Bacillus radiobacter
Azotobacter chroococcum

Agar.	15.0 gm.
Colloid (Soil).	2.0 gm.
Distilled water	1000.0 cc.

MEDIUM 77

Azotobacter chroococcum

Agar.	15.0 gm.
Mannitol.	10.0 gm.
K_2HPO_4.	0.5 gm.
$MgSO_4.7H_2O$.	0.2 gm.
NaCl.	0.2 gm.
$MnSO_4.4H_2O$.	trace
$FeCl_3.6H_2O$.	trace
Distilled water	1000.0 cc.

TABLE XII (Cont.)

MEDIUM 79

Rhizobium leguminosarum
and
Bacillus radiobacter

Agar.	15.0 gm.
Mannitol.	10.0 gm.
K_2HPO_4.	0.5 gm.
$MgSO_4.7H_2O$.	0.2 gm.
NaCl.	0.1 gm.
$CaCO_3$	3.0 gm.
Yeast water (pH 6.8).	100.0 cc.
Distilled water	900.0 cc.

MEDIUM X

Rhizobium leguminosarum
Bacillus radiobacter
Azotobacter chroococcum

Agar.	15.0 gm.
Distilled water	1000.0 cc.

MEDIUM XX

Rhizobium leguminosarum
Bacillus radiobacter
Azotobacter chroococcum

Agar.	15.0 gm.
Yeast water (pH 6.8).	100.0 cc.
Distilled water	1000.0 cc.

The first part of the work consisted in observing the growth of colonies of Rhizobium leguminosarum, Bacillus radiobacter and Azotobacter chroococcum on the various media. The procedure consisted in pouring the sterile medium into sterile petri dishes and inoculating with one cc. suspensions of pure cultures of the organisms. These petri dishes were then incubated for a period of 7 days and the number and appearance of colonies recorded.

The mixed cultures of anaerobic organisms were obtained by sucking medium inoculated with the soil suspension into sterile glass tubing of about 1 mm. inside diameter and 30 cm. long after which the ends were sealed and the organisms were allowed to incubate for 2 to 4 days at room temperature. Bubbles appearing in the tubes after this incubation period were considered to be due to gas produced by anaerobic or facultative anaerobic organisms. When a culture was needed these tubes were broken open and a suspension made from the liquid-like globules and this suspension was used for all of the anaerobic work.

The results in table XIII show the effect of soil colloids on the growth of pure cultures of Rhizobium leguminosarum, Bacillus radiobacter and Azotobacter

TABLE XIII

SOIL COLLOIDS AS NUTRIENTS FOR BACTERIAL DEVELOPMENT

Medium Used	Organisms		
	Rhizobium leguminosarum	Bacillus radiobacter	Azotobacter chroococcum
1A	+++	+++	
2A	+++++	+++	
1			++++
2			+++++
3	++	++	++
79	+++	+++	
77			++++
X	+	+	+
XX	+	+	+

Key:

+++++ - plate completely overgrown in 7 days
++++ - plate well covered with colonies in 7 days
+++ - about half of plate covered in 7 days
++ - a few scattered colonies
+ - some growth

chroococcum. The relative amount of growth made by each of these organisms is shown by + signs. One + sign was used to designate some growth, two signs designated a few scattered colonies; three showed about half the plate covered in 7 days; four showed the plate well covered in 7 days, and where five signs were used the plates were completely overgrown in 7 days. The medium first used was called No. 1A and was used for the Rhizobium leguminosarum and Bacillus radiobacter. It differed from the regular medium on which these organisms are grown only in the mannitol content. In this medium 2 grams of soil colloid were used in place of the 10 grams of mannitol used in each liter of medium prepared. This medium promoted good growth in the organisms as was indicated by the fact that the plates were well covered with colonies after 7 days' growth.

The medium designated as 2A was used for the same organisms. It differed from medium 1A in that 10 grams of mannitol were added to each liter of the solution. The organisms responded best to this medium, completely overgrowing the plate in the 7-day period. The results obtained from the use of these two media would seem to indicate that the colloids are capable of supplying some of the nutrients necessary for the growth

of these two organisms. The medium designated as No. 1 was used for growing a pure culture of Azotobacter chroococcum. It differed from the regular medium recommended only in that it had 2 grams of soil colloid per liter of medium in place of 10 grams of mannitol. The results show that it gave a very satisfactory growth of the organisms.

Medium 2 consisted of 1000 cc. of medium 1 plus 10 grams of mannitol. Growth on this medium was better than on medium 1, but the growth of Azotobacter was very good on both of these media.

Medium 3 contained only 15 grams of agar and 2 grams of soil colloids per liter of distilled water. This medium was not enriched by any nutrients other than those found in the colloids and agar. All three organisms were grown on this medium but only a few scattered colonies developed in each case.

It has been claimed by some investigators that agar contains enough nitrogen and possibly other minerals to support a fair growth of these organisms. Therefore, it was considered desirable to test the growth of these organisms when only agar and distilled water were used in the medium and when only agar, yeast-water and distilled water were used. It was found that the growth of

all the organisms on these two media was very slight and in some cases negligible. The ordinary culture media prescribed by Fred and Waksman (29) for these three soil organisms were tried for comparison with the agar and yeast-water agar media. The organisms did not make as good growth on the prescribed media as they did on the various media in which the soil colloids and the mannitol were used. From these results it would seem that the soil colloids are of real benefit to the growth of organisms in the soil. Probably these colloidal particles offer the most nearly optimum conditions in the soil for the growth of the organisms and no doubt the organisms may be found clustered around the various minute colloidal particles. The fact that the base exchange complex is closely related to the colloidal matter shows that the colloids and the solution surrounding the colloids may be very stimulating both to the aerobic and anaerobic bacteria.

The gas production by a mixed culture of anaerobic organisms inoculated into a medium containing colloids and dextrose and one containing soil and dextrose in shown in table XIV. In both cases dextrose was added at the rate of one per cent and the gas produced by the organisms was measured at various intervals in millimeters of pressure

TABLE XIV

GAS PRODUCTION BY ANAEROBES

Time in Hours	Colloids + Dextrose	Soil + Dextrose
	mm.	mm.
0	0.00	0.00
	0.25	0.30
	1.00	0.44
	1.49	0.46
4	1.99	0.50
	2.35	0.50
	2.74	0.51
	3.00	0.60
8	3.27	0.85
	3.70	0.64
	3.95	0.65
	3.92	0.65
12	4.16	0.87
	4.12	0.70
	4.60	0.90
	4.65	1.00
16	4.75	1.25
	4.95	1.01
	5.25	0.95
	5.00	0.97
20	5.15	1.15
	5.30	1.15
	5.35	1.20
	5.48	1.35
24	5.50	1.37
	5.50	1.45
	5.70	1.45
	5.70	1.45
28	5.75	1.60
	5.80	2.00
	5.90	1.91
	5.92	1.95
32	5.99	2.15
	5.89	2.25
	5.89	2.40
	5.99	2.75
36	5.99	2.65

on the Barcroft differential manometer. For every determination a manometer containing either soil and dextrose or colloids and dextrose but not inoculated was run as a blank. The reading of this manometer was subtracted from the reading of the manometer which had the inoculated soil or colloid and dextrose media. The colloid medium inoculated with the anaerobes produced from two to three times as much gas as the same amount of soil inoculated with anaerobes. The gas production from the soil and from the colloid are shown graphically in figure 12. The anaerobes lagged a little during the first hour and then made very rapid growth during the next six hours as indicated by gas production. After 6 hours, growth gradually decreased until at the end of 36 hours there was no increase. In the other case, the soil inoculated with anaerobes made rapid growth during the first hour but growth decreased during the next 15 to 25 hours, and then increased again regularly until the end of 36 hours although they did not approach the maximum growth made by the anaerobic organisms on the colloids. The colloids either stimulated gas production by furnishing more materials which could be used by the organisms or by being a superior habitat and allowing for a greater number of organisms to develop, possibly because of increased surface.

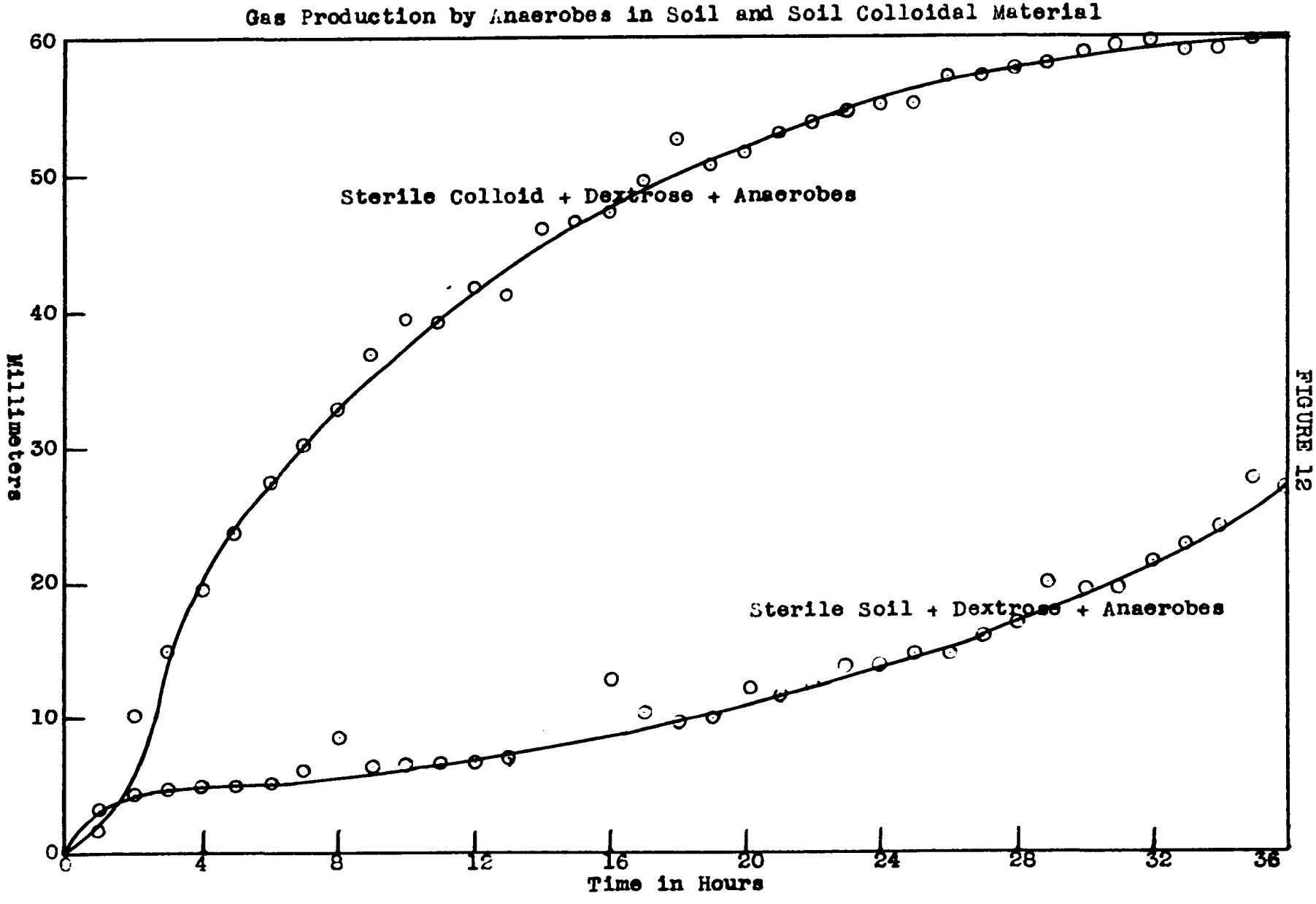

Gas Production by Anaerobes in Soil and Soil Colloidal Material
Sterile Colloid + Dextrose + Anaerobes
Sterile Soil + Dextrose + Anaerobes
Millimeters
Time in Hours
0
10
20
30
40
50
60
4
8
12
16
20
24
28
32
36

FIGURE 12

In another experiment dextrose was added to sterile colloid medium and sterile soil medium, both media being kept sterile and inoculated with a culture of anaerobic organisms isolated from a Webster silty clay loam. The results obtained in this experiment are shown in table XV and Figure 13. The sterile colloid and soil and the colloid and the soil, not sterilized, were inoculated in the same manner.

The growth of these organisms on these various cultural media were obtained by measuring the millimeters of pressure exerted on the liquid in differential manometers. Two such manometers were used, with one being used as a blank throughout the determinations. Prior to this time, Soule (72) and Novy and Roehm (58) have reported the satisfactory use of manometers for studying the growth of organisms and gave suggestions regarding the difficulties that might be encountered.

All the results have been corrected for any changes in temperature or barometric pressure. However, in all cases the temperature was carefully controlled by means of a constant temperature water bath.

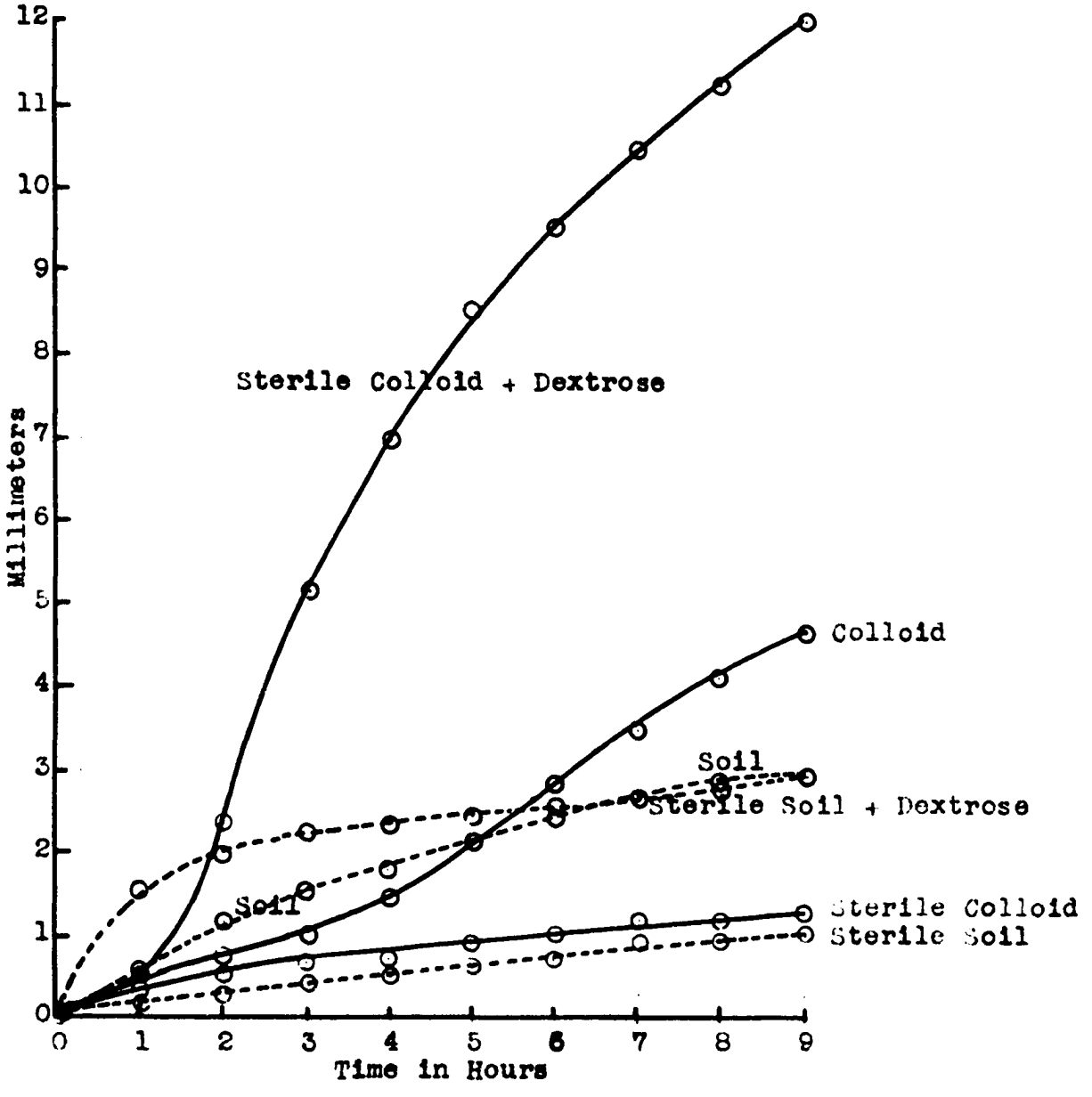
Growth of the organisms on sterile colloid and dextrose was better than on a non-sterile medium as indicated by the amount of gas produced. The colloid medium,

TABLE XV

GAS PRODUCTION BY ANAEROBES AND BY MIXED CULTURES

Time in Hours	Sterile Colloid + Dextrose	Sterile Soil + Dextrose	Sterile Colloid	Sterile Soil	Colloid	Soil
0	0.00	0.00	0.00	0.00	0.00	0.00
1	0.05	1.50	0.30	0.20	0.45	0.60
2	2.35	2.00	0.55	0.30	0.75	0.20
3	5.15	2.25	0.70	0.40	1.00	1.50
4	7.00	2.35	0.70	0.50	1.45	1.80
5	8.50	2.45	0.95	0.65	2.15	2.15
6	9.55	2.50	1.05	0.70	2.80	2.40
7	10.40	2.65	1.20	0.95	3.45	2.65
8	11.20	2.80	1.20	0.95	4.10	2.85
9	12.00	2.90	1.30	1.00	4.65	2.90

FIGURE 13
Gas Production by Anaerobes in Soil and
Soil Colloidal Material



not sterilized, gave the next best growth, with sterile soil plus dextrose, sterile colloid and sterile soil following next in order. The high gas production by the anaerobic organisms when inoculated into the sterile colloid plus dextrose medium might be explained on the basis of the greater surface of material exposed for bacterial action, more nearly anaerobic conditions and a greater supply of nutrients.

Discussion

A study was conducted to determine the value of the soil colloids for the growth of soil microorganisms.

In this work colloids were used as nutrients for some of the common aerobic organisms in the soil. They were also used as supplements to the common media used for growing the various organisms.

Soil colloids were tested as a habitat for anaerobic organisms. The Barcroft differential manometer was employed to measure growth of the organisms.

1. Soil colloids when substituted for mannitol in the ordinary media for Rhizobium leguminosarum, Bacillus radiobacter, or Azotobacter chroococcum permitted a very good growth of the organisms. Growth was as good on petri dishes when the soil colloids were used as when the dextrose was employed as a source of energy.

2. Growth was considerably better when the soil colloid was used as the sole source of nutrient in the agar media than when an agar medium without nutrients was used, but in both cases the growth was inferior to that made on the regular media recommended for the three organisms.

3. Growth of all of the organisms was most luxuriant when a combination of the regular media plus the soil colloids was employed.

4. The results indicate that the soil colloids, either stimulate, act as a source of energy or induce better conditions for the three organisms studied.

5. Anaerobic organisms and mixed cultures of aerobic and anaerobic organisms responded by producing more gas when a culture medium of colloids plus dextrose was used than when cultural media consisting of soil plus dextrose or colloids or soil alone were supplied.

6. Indications are that the colloids present favorable conditions for the growth of some anaerobic organisms.

SUMMARY AND CONCLUSIONS

The physical and chemical properties and bacteriological characteristics of a number of soils collected from various parts of Iowa were studied in an effort to determine what the possibilities were of distinguishing soil types in the laboratory.

1. No striking differences were observed in the physical and chemical properties which could be attributed to particular soil types.

2. Characteristic $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ ratios were observed for each soil, but this property would not be considered sufficient to differentiate soil types.

3. Water extracts from soils did not show definite characteristics on which to base soil type separations, neither did the chemical analyses correlate with all of the chemical analyses of the soils.

4. Various ratios of water to soil yielded different amounts of soluble salts. However, not in all cases did the higher dilutions of water to soil yield the most soluble salts.

5. Studies on the base exchange complex of each soil indicated differences but what significance could be attached to some of the slight differences observed is a question.

6. The exchange complex of the Webster silty clay loam was distinctly more reactive than that of the other soils.

7. The bacteriological studies indicate that the soil colloids may have an important function in the life and growth of both the aerobic and anaerobic organisms found in soils.

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